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Frode Ringdal

Texas Instruments, Incorporated

Prepared for:

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Air Force Technical Applications Center

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SPECIAL REPORT NO. 13

EXTENDED ARRAY EVALUATION PROGRAM

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Prepared for

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This report presents results from an evaluation of the discrimination capability of the Norwegian Short and Long Period Array (NORSAR) for Eurasian events. The evaluation was conducted by Texas Instruments Incorporated at the Seismic Data Analysis Center over the period 1 April 1971 to 30 September 1973.

The following types of discriminants have been analyzed and their performance has been compared:

- Rayleigh wave energy versus m_b (M_s-m_b, AR/m_b)
- Love wave energy versus m_b (M_s-m_b, AL/m_b)
- Short Period P-wave complexity versus m_b (three discriminants)
- Short Period P-wave spectral content versus m_b (Dominant period, Spectral Ratios).

The total data base for this evaluation consists of 233 earthquakes from 1971-1972 and 24 presumed explosions from 1971, 1972, and 1973.

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The following types of discriminants have been analyzed and their performance has been compared:

- Rayleigh wave energy versus m_b ($M_s - m_b$, AR/m_b)
- Love wave energy versus m_b ($M_s - m_b$, AL/m_b)
- Short Period P-wave complexity versus m_b (three discriminants)
- Short Period P-wave spectral content versus m_b (Dominant period, Spectral Ratios).

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TABLE OF CONTENTS

SECTION	TITLE	PAGE
	ABSTRACT	iii
I.	INTRODUCTION	I-1
II.	NORSAR DISCRIMINATION RESULTS	II-1
	A. INTRODUCTION	II-1
	B. PERFORMANCE OF INDIVIDUAL DISCRIMINANTS	II-3
	C. PERFORMANCE OF MULTIPLE DISCRIMINANTS	II-32
III.	SUMMARY AND CONCLUSIONS	III-1
IV.	REFERENCES	IV-1
	APPENDIX A	A-1

LIST OF FIGURES

FIGURE	TITLE	PAGE
I-1	NORSAR SHORT AND LONG PERIOD ARRAY	I-2
I-2	DISTRIBUTION BY DATA SOURCE OF PROCESSED EVENTS	I-10
I-3	DISTRIBUTION OF PROCESSED EVENTS AS A FUNCTION OF EPICENTRAL DISTANCE FROM NORSAR	I-12
II-1	ILLUSTRATION OF A METHOD TO MEASURE THE SEPARATION BETWEEN TWO POINT SETS IN A PLANE	II-2
II-2	M_s(RAYLEIGH) VERSUS m_b DISCRIMINANT	II-4
II-3	M_s(LOVE) VERSUS m_b DISCRIMINANT	II-5
II-4	AR(RAYLEIGH) VERSUS m_b DISCRIMINANT	II-6
II-5	AL(LOVE) VERSUS m_b DISCRIMINANT	II-7
II-6	P30 VERSUS m_b DISCRIMINANT	II-8
II-7	AUTOCORRELATION VERSUS m_b DISCRIMINANT	II-9
II-8	ENVELOPE DIFFERENCE VERSUS m_b DISCRIMINANT	II-10
II-9	DOMINANT PERIOD VERSUS m_b DISCRIMINANT	II-11
II-10	SPECTRAL RATIO (1.5 - 5)/(0 - 0.55)Hz	II-12
II-11	SPECTRAL RATIO (1.5 - 5)/(.55 - 1.5)Hz	II-13
II-12	ILLUSTRATION OF THE RELATIONSHIP BETWEEN THE EARTHQUAKE PROBABILITY DISTRIBUTION AND THE NORMALIZED DISTANCE FROM THE SEPARATION LINE	II-20
II-13	LONG PERIOD TIME DOMAIN PLOT FOR EVENT KAZ/356/06N	II-22

LIST OF FIGURES
(continued)

FIGURE	TITLE	PAGE
II-14	SHORT PERIOD TIME DOMAIN PLOT FOR EVENT KAZ/356/06N	II-23
II-15	LONG PERIOD TIME DOMAIN PLOT FOR EVENT WKZ/233/02N	II-24
II-16	SHORT PERIOD TIME DOMAIN PLOT FOR EVENT WKZ/233/02N	II-25
II-17	SHORT PERIOD TIME DOMAIN PLOT FOR EVENT EK1/345/04N	II-27
II-18	SHORT PERIOD TIME DOMAIN PLOT FOR EVENT EKZ/227/01N	II-28
II-19	AR VERSUS P30 DISCRIMINANT	II-36
II-20	AR VERSUS SPECTRAL RATIO (1.5 - 5)/(0 - 0.55)Hz DISCRIMINANT	II-37
II-21	AL VERSUS P30 DISCRIMINANT	II-38
II-22	AL VERSUS SPECTRAL RATIO (1.5 - 5)/(0 - 0.55)Hz DISCRIMINANT	II-39

LIST OF TABLES

TABLE	TITLE	PAGE
I-1	EVENT PARAMETERS (PRESUMED EXPLOSIONS)	I-3
I-2	EVENT PARAMETERS (EARTHQUAKES)	I-4
I-3	DETECTION PERFORMANCE OF THE NORSAR SP AND LP ARRAYS FOR THE REFERENCE EVENT SET	I-16
II-1	PERFORMANCE OF INDIVIDUAL DISCRIMINANTS FOR PRESUMED EXPLOSIONS	II-15
II-2	PERFORMANCE OF INDIVIDUAL DISCRIMINANTS FOR EARTHQUAKES OF $m_b \geq 4.4$	II-16
II-3	PROBABILITIES OF CORRECT IDENTIFICATION (SHALLOW EARTHQUAKE VERSUS PRESUMED EXPLOSION) BY INDIVIDUAL DISCRIMINANTS FOR EURASIAN EVENTS	II-30
II-4	CORRELATION COEFFICIENTS BETWEEN DISCRIMINANT VALUES FOR EURASIAN EARTHQUAKES	II-33
II-5	PROBABILITIES OF CORRECT IDENTIFICATION (SHALLOW EARTHQUAKE VERSUS PRESUMED EXPLOSION) FOR DISCRIMINANTS COMBINED WITH M_s(RAYLEIGH) - m_b	II-35
A-1	DISCRIMINATION STATISTICS (PRESUMED EXPLOSIONS	A-2
A-2	DISCRIMINATION STATISTICS (EARTHQUAKES)	A-3

SECTION I
INTRODUCTION

This report presents the results of an evaluation of the capability of the short and long period Norwegian Seismic Array (NORSAR) to discriminate between Eurasian earthquakes and presumed explosions. It complements the analyses of the individual performance of various discriminants presented in Special Report No. 11, (Ringdal and Whitelaw, 1973) and Special Report No. 12, (Laun, Shen, and Swindell, 1973) for the NORSAR short and long period arrays, respectively.

The NORSAR array is centered about 100 km north of Oslo, Norway, at a latitude of 60.8°N and a longitude of 10.8°E. It consists of 22 subarrays, each with 6 short period and one 3-component long period sensors (Figure I-1). The diameter of each subarray is 8-10 km; the full array has an aperture of approximately 100 km.

The results presented in this report are based upon Eurasian earthquakes occurring between 30 April, 1971 and 31 July, 1972 and Eurasian presumed explosions from 1971, 1972, and 1973. Essentially, the data base consists of events that were processed for both the short period and long period evaluations (Special Reports No. 11 and 12, 1973). However, a few additional presumed explosions from 1972 and 1973 have been analyzed in order to increase the common event population. The complete data base is listed in Tables I-1 and I-2. Total number of events is 257, 24 of which are presumed explosions. All of the earthquakes are either shallow or of unknown depth.

Figure I-2 presents a breakdown of the processed events by information source. Our events have been selected from seismic bulletins provided by four different organizations:

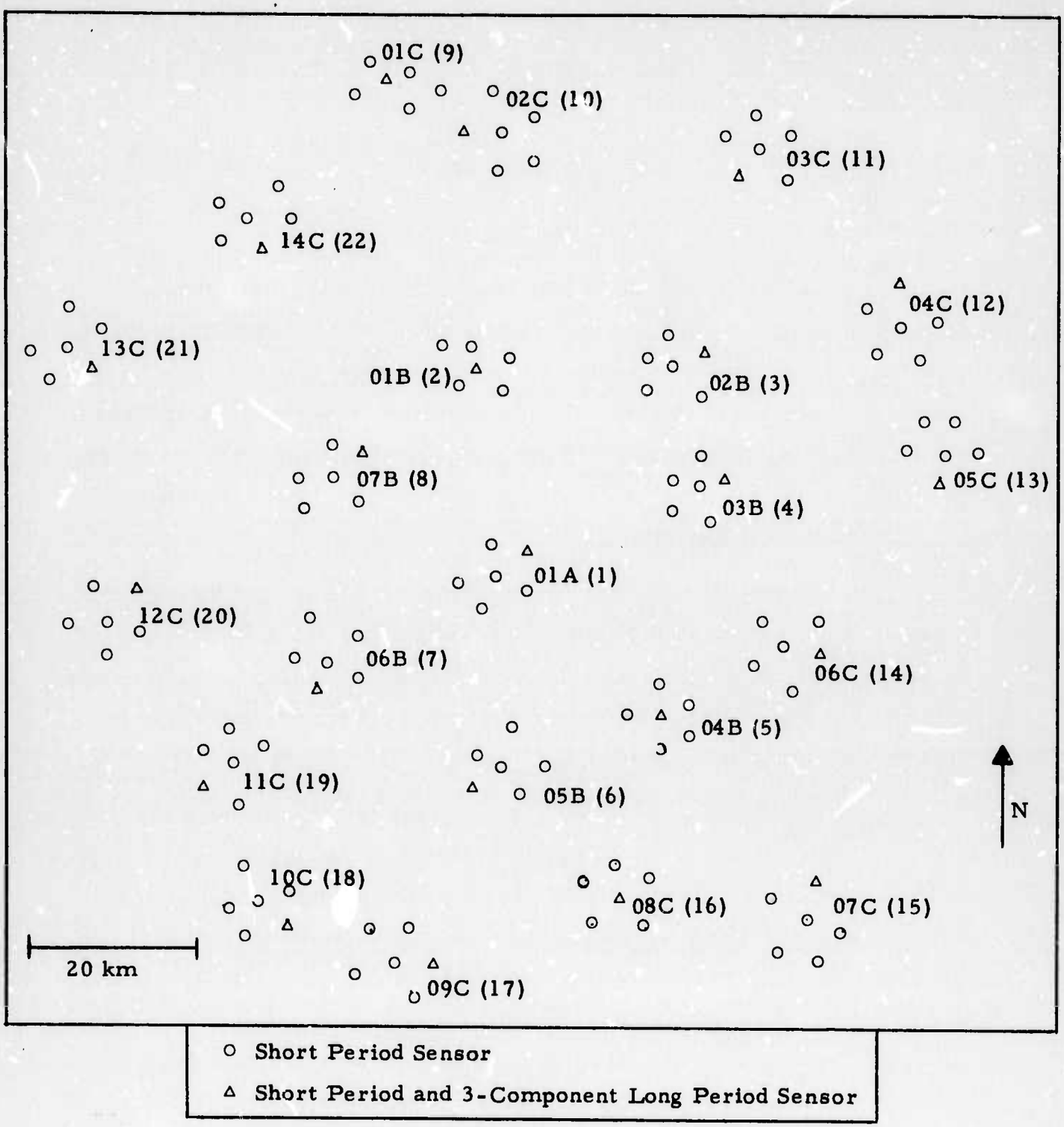

FIGURE I-1

NORSAR SHORT AND LONG PERIOD ARRAY

TABLE I-1

EVENT PARAMETERS (PRESUMED EXPLOSIONS)

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MB	SOURCE RLTN	COMMENT
KAZ/145/04N	05/25/71	04.02.57	49.8N	78.2E	0	5.2	P	
KAZ/157/04N	06/06/71	04.02.57	50.0N	77.8E	0	5.5	P	
KAZ/170/04N	06/19/71	04.03.57	50.0N	77.7E	0	5.5	P	
URA/191/16N	07/10/71	16.59.59	64.2N	55.2E	0	5.3	P	NL
KAZ/282/06N	10/09/71	06.02.57	50.0N	77.7E	0	5.4	P	
EKZ/294/06N	10/21/71	06.02.57	50.0N	77.6E	0	5.6	P	
EKZ/333/06N	11/29/71	06.02.57	49.9N	78.1E	0	5.5	P	
EKZ/349/07N	12/15/71	07.52.59	50.0N	77.9E	0	4.9	P	NL
KAZ/356/06N	12/22/71	06.59.56	47.9N	48.2E	0	6.0	P	
EKZ/364/06N	12/30/71	06.20.58	49.7N	78.1E	0	5.8	P	
EKZ/041/05N	02/10/72	05.02.57	50.0N	78.9E	0	5.5	P	
KAZ/070/04N	03/10/72	04.56.57	49.8N	78.2E	0	5.5	I	
EKZ/088/04N	03/28/72	04.21.57	49.7N	78.2E	0	5.2	P	
EKZ/188/01N	07/06/72	01.02.58	49.7N	78.0E	0	4.4	P	NL
EKZ/229/03N	08/16/72	03.16.57	49.8N	78.1E	0	5.2	P	
WKZ/233/02N	08/20/72	02.59.58	49.5N	48.2E	0	5.7	P	
EKZ/246/08N	09/02/72	08.56.58	50.0N	77.7E	0	5.1	P	NL
SWR/277/08N	10/03/72	08.59.58	46.8N	45.0E	0	5.8	P	
EKZ/307/01N	11/02/72	01.26.58	49.9N	78.8E	0	6.2	P	
EKZ/345/04N	12/10/72	04.26.58	49.8N	78.1E	0	5.7	P	
EKZ/047/05N	02/16/73	05.02.58	49.8N	78.2E	0	5.6	P	
EKZ/204/01N	07/23/73	01.22.58	50.0N	78.9E	0	6.3	P	
EKZ/227/01N	08/15/73	01.59.58	42.7N	67.4E	0	5.3	P	
EKZ/240/03N	08/28/73	02.59.58	50.5N	68.4E	0	5.3	P	

ABBREVIATIONS

P : Reported by PDE

I : Reported by ISM

NL : No Long Period signal detected on NORSAR data (TI analyst decision)

TABLE I-2

EVENT PARAMETERS (EARTHQUAKES)
(PAGE 1 OF 6)

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MB	SOURCE PLTN	COMMENT	
TIB/123/00N	05/03/71	00.33.22	30.9N	84.5E	16	5.4	P		
TUR/126/04N	05/06/71	04.24.33	39.0N	29.7E	23	4.6	P		
CAS/135/04N	05/15/71	04.53.05	35.1N	49.1E	NOR	4.6	P		
TUR/143/01N	05/23/71	01.02.54	37.6N	30.1E	NOR	4.4	P		
TAC/147/00N	05/27/71	00.30.27	38.3N	69.0E	36	4.8	P		
NEC/156/10N	06/05/71	10.21.28	37.3N	113.7E	NOR	4.7	P		
TUR/161/09N	06/10/71	09.31.54	39.1N	29.6E	NOR	4.9	P		
KAM/166/14N	06/15/71	14.04.08	52.8N	160.8E	55	5.1	P		
KIR/166/23N	06/15/71	23.17.33	41.6N	79.2E	NOR	4.9	P		
KIR/170/17N	06/19/71	17.23.02	41.5N	79.3E	NOR	5.2	P		
KUR/190/16N	07/09/71	16.44.15	43.5N	147.7E	46	4.9	P		
KUR/191/03N	07/10/71	03.05.00	43.6N	147.7E	36	4.8	P		
KUR/191/09N	07/10/71	09.01.34	45.0N	150.5E	NOR	4.6	P		
BLS/210/19N	07/29/71	19.40.10	39.6N	30.4E	NOR	4.5	P		
KUR/213/02N	08/01/71	02.06.06	50.4N	156.8E	20	5.6	P		
SIN/221/01N	08/09/71	01.03.16	42.1N	83.4E	NOR	4.2	P		
SIN/241/15N	08/29/71	15.16.56	36.5N	78.5E	NOR	5.0	P		NL
TUR/251/22N	09/08/71	22.35.15	41.1N	43.8E	33	4.8	P		
SIB/001/15N	01/01/72	15.04.19	59.7N	153.8E	NOR	4.1	S	NS	NL
KUR/001/16N	01/01/72	16.55.06	50.7N	155.8E	NOR	4.6	S		
KUR/001/18N	01/01/72	18.13.54	49.4N	156.5E	50	4.0	S		
GRE/002/09N	01/02/72	09.17.53	37.9N	20.7E	NOR	4.2	S		
SIN/002/10N	01/02/72	10.27.35	41.8N	84.5E	19	5.2	S		
KAM/003/06N	01/03/72	06.36.38	51.6N	159.4E	NOR	4.8	P		
KAM/003/19N	01/03/72	19.26.43	52.0N	159.0E	NOR	4.5	N	MBN	
KAM/004/02N	01/04/72	02.29.18	55.6N	161.2E	NOR	4.3	S		
KAM/004/10N	01/04/72	10.42.31	55.6N	163.8E	NOR	4.4	S		NL
TAI/004/12N	01/04/72	12.15.17	22.4N	122.2E	NOR	4.6	P		
KUR/005/02N	01/05/72	02.16.10	43.8N	147.2E	NOR	4.5	P		
AUS/005/04N	01/05/72	04.57.41	47.8N	16.2E	11	4.0	P		
TAC/005/12N	01/05/72	12.02.54	37.8N	73.1E	NOR	4.5	S		
KOM/005/14N	01/05/72	14.26.48	56.6N	169.4E	NOR	4.0	S	NS	NL
KAM/005/16N	01/05/72	16.09.50	57.3N	160.5E	25	3.9	S		
TAI/006/06N	01/06/72	06.33.34	23.3N	123.4E	NOR	4.7	P	MBN	
SWR/007/20N	01/07/72	20.37.32	44.1N	45.1E	NOR	4.2	S		NL
KOM/009/03N	01/09/72	03.23.06	54.4N	164.4E	NOR	3.6	S	NS	NL
KAM/009/14N	01/09/72	14.00.59	55.7N	163.6E	NOR	4.3	S		
KUR/009/14N	01/09/72	14.47.46	45.1N	148.4E	NOR	3.8	S	NS	NL
KOM/011/08N	01/11/72	08.54.34	54.7N	168.2E	28	3.9	S		NL
GRE/012/13N	01/12/72	13.51.20	35.0N	23.5E	NOR	4.9	P	MBN	
KAM/012/20N	01/12/72	20.20.15	55.6N	163.9E	NOR	4.8	S		
SIB/013/17N	01/13/72	17.24.07	61.9N	147.1E	NOR	5.3	S		
SIB/014/03N	01/14/72	03.20.20	67.5N	171.5E	NOR	3.9	P	MBN	
IRA/014/22N	01/14/72	22.10.04	32.9N	46.9E	NOR	5.1	P	MBN	
KUR/015/00N	01/15/72	00.58.33	49.6N	155.0E	NOR	3.9	S	NS	NL

TABLE I-2

EVENT PARAMETERS (EARTHQUAKES)
(PAGE 2 OF 6)

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MB	SOURCE PLTN	COMMENT	
IRA/018/21N	01/18/72	21.12.02	37.5N	48.7E	NOR	4.0	P	MBN	
DOD/020/02N	01/20/72	02.15.07	36.5N	27.1E	NOR	4.0	S		
KUR/022/01N	01/22/72	01.41.24	50.0N	152.0E	NOR	4.2	P	MBN	
TUR/022/17N	01/22/72	17.17.31	37.6N	29.9E	13	4.4	P		
KAM/025/10N	01/25/72	10.02.40	53.9N	160.9E	NOR	4.6	P		NL
CRE/026/12N	01/26/72	12.54.39	34.5N	25.5E	NOR	4.0	S		
KAM/027/20N	01/27/72	20.37.28	55.7N	162.3E	40	3.8	S		NL
FCS/028/04N	01/28/72	04.22.28	27.5N	126.5E	NOR	4.4	S		
KIR/028/20N	01/28/72	20.29.19	43.0N	78.0E	NOR	4.4	P	MBN	
ERS/028/21N	01/28/72	21.50.00	45.0N	136.0E	NOR	4.0	N		NL
KUR/028/23N	01/28/72	23.42.51	46.3N	157.3E	NOR	3.8	S		
IRA/029/09N	01/29/72	09.50.58	29.0N	62.0E	NOR	3.9	N		
KAM/032/10N	02/01/72	10.16.09	55.8N	162.8E	NOR	4.1	S		NL
KUR/033/09N	02/02/72	09.58.51	46.3N	146.4E	NOR	3.6	S		NL
KUR/033/17N	02/02/72	17.56.39	50.7N	160.1E	NOR	3.6	S		NL
YUN/034/07N	02/03/72	07.22.49	23.4N	102.4E	NOR	4.5	P		
BAI/035/03N	02/04/72	03.34.56	51.4N	118.0E	NOR	4.2	S		
ITA/035/09N	02/04/72	09.18.32	43.0N	13.2E	23	4.4	P		
IRA/041/09N	02/10/72	09.04.09	29.6N	50.9E	NOR	3.9	P		
IRA/041/16N	02/10/72	16.40.16	29.5N	50.9E	49	4.1	P		
SIN/042/05N	02/11/72	05.55.46	29.9N	77.4E	23	4.0	P		
TIB/042/12N	02/11/72	12.20.42	29.0N	87.0E	NOR	4.3	N		NL
KAM/042/21N	02/11/72	21.36.17	56.1N	162.9E	44	4.6	P		
KUR/044/05N	02/13/72	05.24.57	43.5N	147.0E	NOR	3.9	S		NL
GRE/044/13N	02/13/72	13.07.11	37.1N	24.0E	27	4.5	P		
KOM/044/22N	02/13/72	22.36.54	55.2N	165.5E	NOR	3.9	S		
KUR/046/16N	02/15/72	16.45.22	45.0N	153.0E	NOR	4.1	S		
GRE/047/00N	02/16/72	00.42.24	36.5N	24.2E	NOR	4.5	P		
KUR/049/18N	02/18/72	18.02.34	43.6N	147.8E	36	4.7	S		
SIN/051/10N	02/20/72	10.22.46	38.5N	90.5E	16	3.9	I	MBN	
KAM/051/20N	02/20/72	20.06.11	50.8N	141.5E	NOR	4.1	I		
KAM/052/22N	02/21/72	22.00.59	54.4N	161.3E	NOR	4.8	I		
YUG/052/23N	02/21/72	23.02.55	41.0N	22.3E	NOR	4.0	I		NL
MON/053/01N	02/22/72	01.52.36	49.0N	115.0E	NOR	4.1	I		NL
HIN/053/08N	02/22/72	08.14.26	36.6N	69.6E	NOR	4.0	I	MBN	
KUR/054/03N	02/23/72	03.42.41	43.9N	148.3E	29	4.0	I		
KAM/054/19N	02/23/72	19.37.29	55.0N	163.0E	NOR	3.7	I	NS	NL
KUR/055/10N	02/24/72	10.19.37	49.8N	155.7E	NOR	5.0	I		
KUR/055/18N	02/24/72	18.17.34	49.0N	153.0E	NOR	3.5	I	NS	NL
KUR/056/19N	02/25/72	19.49.29	46.0N	147.0E	NOR	3.9	I		NL
WRS/056/22N	02/25/72	22.24.49	50.0N	38.0E	NOR	3.7	I		NL
KUR/056/22N	02/25/72	22.43.07	49.2N	156.0E	NOR	4.0	I		
KUR/057/05N	02/26/72	05.58.22	46.9N	152.6E	NOR	4.0	I		
KAM/057/09N	02/26/72	09.04.32	55.0N	162.0E	NOR	3.3	I	NS	NL
ERS/057/15N	02/26/72	15.06.42	53.3N	139.7E	NOR	3.9	I	MBN	NL

TABLE I-2

EVENT PARAMETERS (EARTHQUAKES)
(PAGE 3 OF 6)

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MB	SOURCE BLTN	COMMENT	
YUN/057/18N	02/26/72	18.56.13	27.1N	100.9E	NOR	4.7	I		
LOI/058/08N	02/27/72	08.42.59	88.0N	74.0W	NOR	3.3	I	NS	NL
LOM/058/10N	02/27/72	10.03.03	87.0N	53.5W	NOR	4.9	I		
LOM/058/11N	02/27/72	11.03.19	90.0N	95.0W	NOR	3.5	I		NL
LOM/058/17N	02/27/72	17.50.25	86.2N	77.2W	NOR	4.4	I		
BAI/058/22N	02/27/72	22.15.03	55.0N	93.2E	NOR	4.5	I		
KUR/059/01N	02/28/72	01.04.22	46.0N	148.0E	NOR	4.2	I	NS	NL
PAK/059/05N	02/28/72	05.18.56	36.7N	71.4E	NOR	4.2	I	MBN	
KAM/059/11N	02/28/72	11.35.31	56.0N	163.0E	NOR	4.1	I	NS	NL
AFG/059/18N	02/28/72	18.12.35	36.0N	68.7E	NOR	4.4	I	MBN	
KAM/059/20N	02/28/72	20.04.00	56.1N	164.2E	NOR	3.6	I	NS	NL
IRQ/060/08N	02/29/72	09.02.51	32.8N	46.6E	NOR	4.0	I	MBN	
IRA/062/14N	03/02/72	14.10.13	31.6N	42.1E	NOR	4.0	I	MBN	NL
ALM/062/19N	03/02/72	19.57.42	43.0N	76.0E	NOR	3.5	I	MBN	NL
KAM/063/00N	03/03/72	00.39.23	53.0N	159.2E	NOR	4.1	I		NL
KOM/063/08N	03/03/72	08.13.55	55.8N	163.9E	NOR	4.1	I		NL
YUG/063/21N	03/03/72	21.26.51	44.7N	18.4E	32	4.4	I		
KUR/063/23N	03/03/72	23.10.41	50.2N	155.7E	NOR	4.5	I		
SIN/064/04N	03/04/72	04.00.09	40.2N	79.0E	NOR	4.5	I		
KAM/066/06N	03/06/72	06.05.08	53.5N	160.9E	NOR	3.9	I	NS	NL
KUR/066/09N	03/06/72	09.59.09	45.0N	150.0E	NOR	3.7	I		NL
OKH/066/19N	03/06/72	19.13.25	56.0N	140.0E	NOR	4.2	I		NL
CHI/066/23N	03/06/72	23.17.53	40.0N	103.0E	NOR	4.5	I	NS	NL
YUG/067/05N	03/07/72	05.21.21	43.0N	21.0E	NOR	2.7	I	MBN	NL
OKH/068/02N	03/08/72	02.38.11	51.2N	151.9E	NOR	4.2	I		NL
IRA/068/21N	03/08/72	21.49.11	27.6N	56.7E	45	4.6	I		
BUL/068/22N	03/08/72	22.04.02	40.8N	22.8E	NOR	3.5	I	MBN	
KUR/070/06N	03/10/72	06.50.18	45.1N	149.5E	NOR	3.7	I		
ARC/071/06N	03/11/72	06.47.07	81.0N	157.0E	NOR	4.3	I	NS	NL
KAS/071/13N	03/11/72	13.31.39	35.0N	76.0E	NOR	4.1	I	MBN	NL
KUR/073/02N	03/13/72	02.11.05	49.0N	158.0E	NOR	3.8	I		NL
AFG/073/05N	03/13/72	05.49.13	37.0N	70.0E	NOR	4.0	I	MBN	NL
TIB/073/18N	03/13/72	18.27.07	34.0N	83.0E	NOR	4.1	I	MBN	NL
TIB/075/06N	03/15/72	06.00.33	30.4N	84.5E	NOR	5.3	I	MBN	
KUR/077/07N	03/17/72	07.49.02	49.0N	156.2E	NOR	5.2	I		
TAC/077/09N	03/17/72	09.17.11	40.1N	69.7E	26	5.2	I		
IRA/077/17N	03/17/72	17.11.28	28.0N	54.0E	NOR	3.9	I	MBN	NL
KAS/077/23N	03/17/72	23.33.37	32.0N	75.0E	NOR	3.5	I	MBN	NL
KAZ/078/07N	03/18/72	07.11.55	47.0N	81.0E	NOR	3.6	I	MBN	
KAM/078/13N	03/18/72	13.52.14	57.0N	163.0E	NOR	3.6	I		NL
KAM/078/18N	03/18/72	18.29.37	50.6N	156.7E	NOR	4.7	I		
OKH/078/19N	03/18/72	19.17.25	54.0N	150.0E	NOR	3.7	I		NL
CAU/079/03N	03/19/72	03.34.31	42.7N	38.1E	NOR	3.9	I		
KUR/080/14N	03/20/72	14.08.12	47.0N	154.0E	NOR	4.0	I	MBN	NL
SIN/080/21N	03/20/72	21.47.55	40.0N	80.0E	NOR	3.4	I	MBN	NL

TABLE I-2

EVENT PARAMETERS (EARTHQUAKES)
(PAGE 4 OF 6)

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MB	SOURCE BLTN	COMMENT	
CKZ/153/01N	06/01/72	01.23.26	52.0N	70.0E	NOR	3.6	S	NS	NL
MON/153/11N	06/01/72	11.22.15	44.0N	103.0E	NOR	3.7	N		
SIN/154/05N	06/02/72	05.11.13	43.0N	81.0E	NOR	3.5	N		NL
SIN/154/06N	06/02/72	06.30.49	42.0N	81.0E	NOR	3.9	N		
TSI/154/16N	06/02/72	16.49.22	36.0N	92.0E	NOR	3.7	N		
CHI/154/20N	06/02/72	20.32.55	28.4N	95.9E	NOR	4.3	P		
RYU/155/02N	06/03/72	02.16.51	23.5N	125.5E	NOR	5.0	P		
IRA/155/08N	06/03/72	08.21.30	29.0N	53.0E	NOR	4.2	N		
IRA/156/03N	06/04/72	03.37.49	30.0N	54.0E	NOR	4.2	N		
KAM/156/07N	06/04/72	07.52.38	53.0N	158.0E	NOR	4.0	S		
KAM/157/04N	06/05/72	04.12.54	56.2N	163.1E	NOR	4.3	P		
GRE/157/10N	06/05/72	10.44.59	37.8N	21.4E	69	4.2	P		
IRA/157/11N	06/05/72	11.17.57	34.0N	46.0E	NOR	3.9	N		
PAK/157/11N	06/05/72	11.52.53	29.8N	70.3E	27	4.8	P		
NEJ/157/19N	06/05/72	19.00.12	86.5N	28.9E	NOR	4.5	S		
KUR/158/06N	06/06/72	06.32.10	49.0N	155.0E	NOR	3.6	S	NS	NL
TAI/160/10N	06/08/72	10.17.44	21.0N	120.2E	NOR	4.9	P		
TUR/160/12N	06/08/72	12.46.15	41.0N	44.0E	NOR	4.1	S		
BUR/160/16N	06/08/72	16.08.06	19.0N	94.0E	NOR	4.3	N		
TIB/160/23N	06/08/72	23.10.12	29.5N	92.3E	64	4.7	P		
CRE/161/07N	06/09/72	07.42.20	34.8N	26.5E	NOR	4.9	P		
PAK/162/11N	06/10/72	11.29.11	29.2N	66.5E	NOR	4.5	P		
KU1/163/23N	06/11/72	23.23.04	48.0N	152.0E	NOR	4.0	S		NL
KU2/163/23N	06/11/72	23.33.44	47.0N	152.0E	NOR	4.3	S		NL
KUR/164/00N	06/12/72	00.19.16	44.0N	148.0E	NOR	3.7	S		NL
IR1/164/13N	06/12/72	13.34.01	33.1N	46.3E	NOR	5.4	P		
IRA/165/00N	06/13/72	00.55.37	33.1N	46.3E	27	5.1	P		
KAM/165/04N	06/13/72	04.53.30	55.0N	162.0E	NOR	3.8	S		NL
CAS/166/00N	06/14/72	00.49.54	40.1N	51.9E	47	4.7	P		
IRA/166/04N	06/14/72	04.34.28	33.0N	46.1E	NOR	5.2	P		
IR2/166/12N	06/14/72	12.35.05	27.0N	56.0E	NOR	3.6	N		NL
GRE/167/00N	06/15/72	00.33.24	38.3N	22.2E	26	4.9	P		
KAM/168/09N	06/16/72	09.54.41	56.0N	161.0E	NOR	4.1	S		NL
KAM/168/22N	06/16/72	22.12.12	53.0N	157.0E	NOR	3.6	S	NS	NL
IRA/168/23N	06/16/72	23.22.27	34.0N	46.0E	NOR	3.7	N		
AUS/169/09N	06/17/72	09.02.48	48.3N	14.5E	NOR	4.3	P		
KUR/169/19N	06/17/72	19.18.21	44.2N	149.1E	64	4.6	P		
TIB/170/04N	06/18/72	04.30.47	33.0N	83.0E	NOR	4.3	N		
KUR/170/09N	06/18/72	09.10.54	48.0N	154.0E	NOR	3.9	S		NL
KU2/171/18N	06/19/72	18.07.53	43.8N	151.5E	NOR	4.5	P		
KUR/171/22N	06/19/72	22.41.42	48.0N	157.0E	NOR	4.1	S	NS	
ERS/172/09N	06/20/72	09.18.09	52.0N	131.0E	NOR	3.7	S	NS	
KAS/172/15N	06/20/72	15.34.37	32.0N	75.0E	NOR	3.6	N		NL
TUR/173/05N	06/21/72	05.06.17	40.2N	30.0E	NOR	4.1	P		
KAM/173/10N	06/21/72	10.42.45	54.0N	161.0E	NOR	4.3	S		

TABLE I-2

EVENT PARAMETERS (EARTHQUAKES)
(PAGE 5 OF 6)

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MB	SOURCE PLTN	COMMENT	
TUR/175/04N	06/23/72	04.25.27	41.0N	30.0E	NOR	3.7	S		
GRE/175/07N	06/23/72	07.18.14	37.0N	21.0E	NOR	3.4	N		
YUG/177/04N	06/25/72	04.50.15	44.0N	15.8E	NOR	3.7	P		
HIN/177/07N	06/25/72	07.55.45	36.3N	69.6E	46	4.7	P		
KAM/177/17N	06/25/72	17.35.50	54.0N	160.0E	NOR	4.1	S	NS	
TAI/178/08N	06/26/72	08.08.25	21.1N	120.3E	NOR	5.0	P		
KAM/178/17N	06/26/72	17.32.32	56.0N	158.0E	NOR	3.6	S	NS	NL
HIN/178/20N	06/26/72	20.59.03	36.0N	69.0E	NOR	3.7	N		
PAK/179/06N	06/27/72	06.39.44	29.7N	70.3E	12	5.5	P		
HIN/179/15N	06/27/72	15.59.35	36.3N	69.5E	53	5.1	P		
YUG/180/01N	06/28/72	01.43.56	43.0N	20.5E	NOR	4.6	P		
TSI/180/03N	06/28/72	03.09.59	33.0N	91.0E	NOR	3.6	N		
KOM/180/06N	06/28/72	06.00.22	55.0N	164.0E	NOR	3.4	S	NS	NL
CYP/180/09N	06/28/72	09.16.55	35.0N	32.0E	NOR	4.3	N		NL
UAR/180/09N	06/28/72	09.49.35	27.6N	33.8E	15	5.6	P		
KAM/180/14N	06/29/72	14.58.49	53.0N	161.0E	NOR	3.9	S		
CKZ/181/00N	06/29/72	00.41.02	54.0N	69.0E	NOR	3.7	S		
AFG/181/03N	06/29/72	03.32.11	38.9N	71.4E	53	4.6	P		
TAI/182/18N	06/30/72	18.57.43	24.3N	121.1E	NOR	4.9	P		
IRA/182/20N	06/30/72	20.21.33	30.0N	53.0E	NOR	4.0	N		
KOM/183/02N	07/01/72	02.10.18	54.0N	166.0E	NOR	3.4	S		NL
IRA/184/12N	07/02/72	12.56.07	30.1N	50.8E	31	5.4	P		
IRA/184/14N	07/02/72	14.05.06	30.0N	50.8E	31	4.6	P		
IRA/185/02N	07/03/72	02.10.00	30.1N	50.8E	38	5.0	P		
KAM/186/13N	07/04/72	13.52.19	55.0N	163.0E	NOR	4.4	S		
KUR/186/21N	07/04/72	21.47.57	49.0N	151.0E	NOR	3.6	S	NS	
SIN/187/04N	07/05/72	04.09.49	43.6N	87.0E	NOR	4.3	P		
IRA/187/16N	07/05/72	16.29.27	31.0N	52.0E	NOR	4.0	N		
KUR/193/06N	07/11/72	06.58.21	48.4N	154.5E	62	5.2	P		
KUR/197/17N	07/15/72	17.25.37	46.0N	149.0E	NOR	3.5	S		NL
TIB/198/02N	07/16/72	02.20.24	32.5N	95.9E	NOR	5.2	P		
TUR/198/02N	07/16/72	02.46.37	36.0N	44.0E	NOR	5.5	S		
TIB/198/03N	07/16/72	03.40.00	32.6N	95.9E	NOR	4.7	P		
TAI/198/13N	07/16/72	13.47.52	21.0N	122.0E	NOR	4.5	N		
MED/199/03N	07/17/72	03.14.05	34.0N	30.0E	NOR	3.9	S		
KAM/199/08N	07/17/72	08.28.52	55.0N	159.6E	NOR	5.3	P		
KAM/199/11N	07/17/72	11.11.46	57.0N	162.0E	NOR	3.3	S	NS	NL
MED/199/16N	07/17/72	16.15.28	35.0N	22.0E	NOR	3.4	N		
KAM/199/20N	07/17/72	20.50.54	55.1N	159.5E	NOR	4.5	P		
GRE/200/13N	07/19/72	13.45.48	41.6N	23.8E	NOR	4.0	P		
SZE/203/16N	07/21/72	16.11.33	29.8N	102.3E	NOR	4.9	P		
TIB/204/16N	07/22/72	16.41.04	31.4N	91.5E	NOR	5.5	P		
TIB/204/21N	07/22/72	21.00.09	31.4N	91.4E	NOR	4.7	P		
MED/205/18N	07/23/72	18.17.25	33.0N	24.0E	NOR	3.9	S		
TIB/205/23N	07/23/72	23.41.55	31.0N	91.0E	NOR	3.6	N		

TABLE I-2

EVENT PARAMETERS (EARTHQUAKES)
(PAGE 6 OF 6)

EVENT DESIGNATION	DATE	ORIGIN TIME	LAT	LON	DEPTH	MB	SOURCE BLTN	COMMENT
TUR/206/10N	07/24/72	10.22.05	36.0N	42.0E	NOR	4.3	S	
KAM/206/13N	07/24/72	13.09.26	58.0N	162.0E	NOR	4.0	S	
KUR/209/00N	07/27/72	00.20.55	50.0N	159.1E	NOR	5.1	P	
RYU/209/16N	07/27/72	16.41.24	24.0N	132.0E	NOR	5.1	N	
AFG/211/17N	07/29/72	17.10.35	32.0N	68.0E	NOR	3.8	N	
KUR/211/21N	07/29/72	21.07.16	49.0N	156.0E	NOR	4.5	S	
KAM/213/06N	07/31/72	06.40.28	56.2N	162.9E	NOR	4.8	P	
IRA/213/21N	07/31/72	21.01.25	31.0N	52.0E	NOR	3.6	N	

ABBREVIATIONS

P : Reported by PDE

I : Reported by ISM

S : Reported by SDAC/LASA

N : Reported by NTNF/NORSAR

NS : No short period signal detected on NORSAR data (TI analyst decision)

NL : No long period signal detected on NORSAR data (TI analyst decision)

MBN: Bodywave magnitude is based on NORSAR data

NOR: Normal depth - means that focal depth has been restricted at 33 km; i.e. there is not sufficient evidence (such as depth phases) to provide a specific depth estimate.

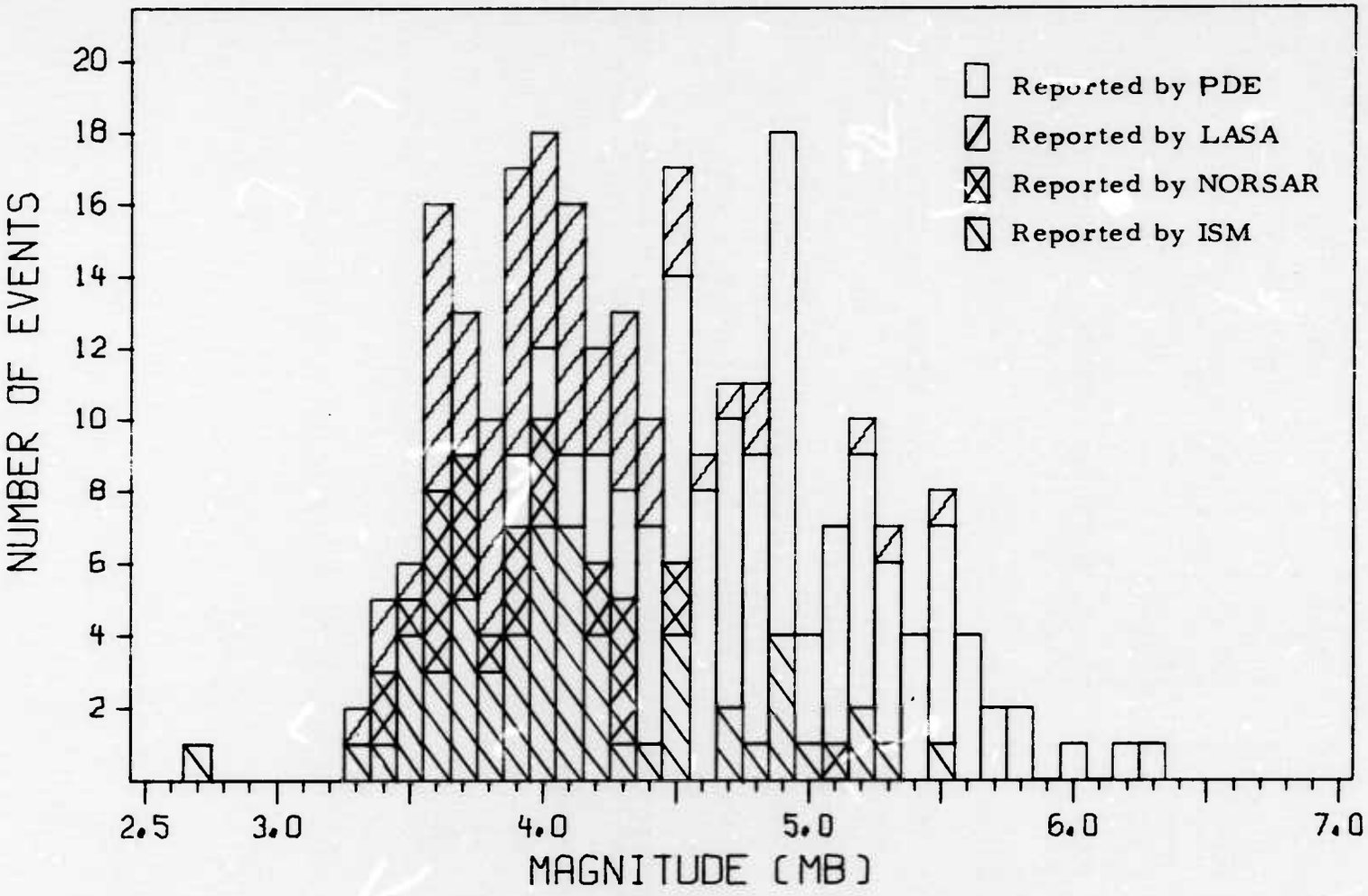

FIGURE I-2

DISTRIBUTION BY DATA SOURCE OF PROCESSED EVENTS

- The PDE listings (Preliminary Determination of Epicenters) issued by the National Oceanic and Atmospheric Administration (NOAA)
- The LASA seismic bulletin issued by the Seismic Data Analysis Center (SDAC)
- The NORSAR seismic bulletin compiled at Kjeller, Norway
- The bulletin from the International Seismic Month (ISM), which covers February 20 to March 19, 1972, and has been compiled at Lincoln Laboratories.

In all cases where an event was reported by more than organization, we selected our source information according to the priority list: ISM, PDE, LASA, NORSAR. As can be seen from Figure I-2, most events of m_b above 4.5 have been reported by PDE, while LASA and NORSAR supply the detection information for most low magnitude events.

Figure I-3 is a histogram showing the distribution of processed events as a function of epicentral distance from NORSAR, and indicating which events are presumed explosions. It is seen that almost all our presumed explosions occur at a distance of about 38 degrees, this corresponds to the Eastern Kazakh region in the Soviet Union. With respect to close-in presumed explosions from Western Russia, the number of events included in this report is much lower than the corresponding number for our SP evaluation. The reason for not processing more of these events is mainly the occurrence of amplitude clipping for these large signals, which has made any measurement of surface-wave magnitudes impossible in many cases.

The earthquake population in our data base may conveniently be divided into three regions where the majority of events are located:

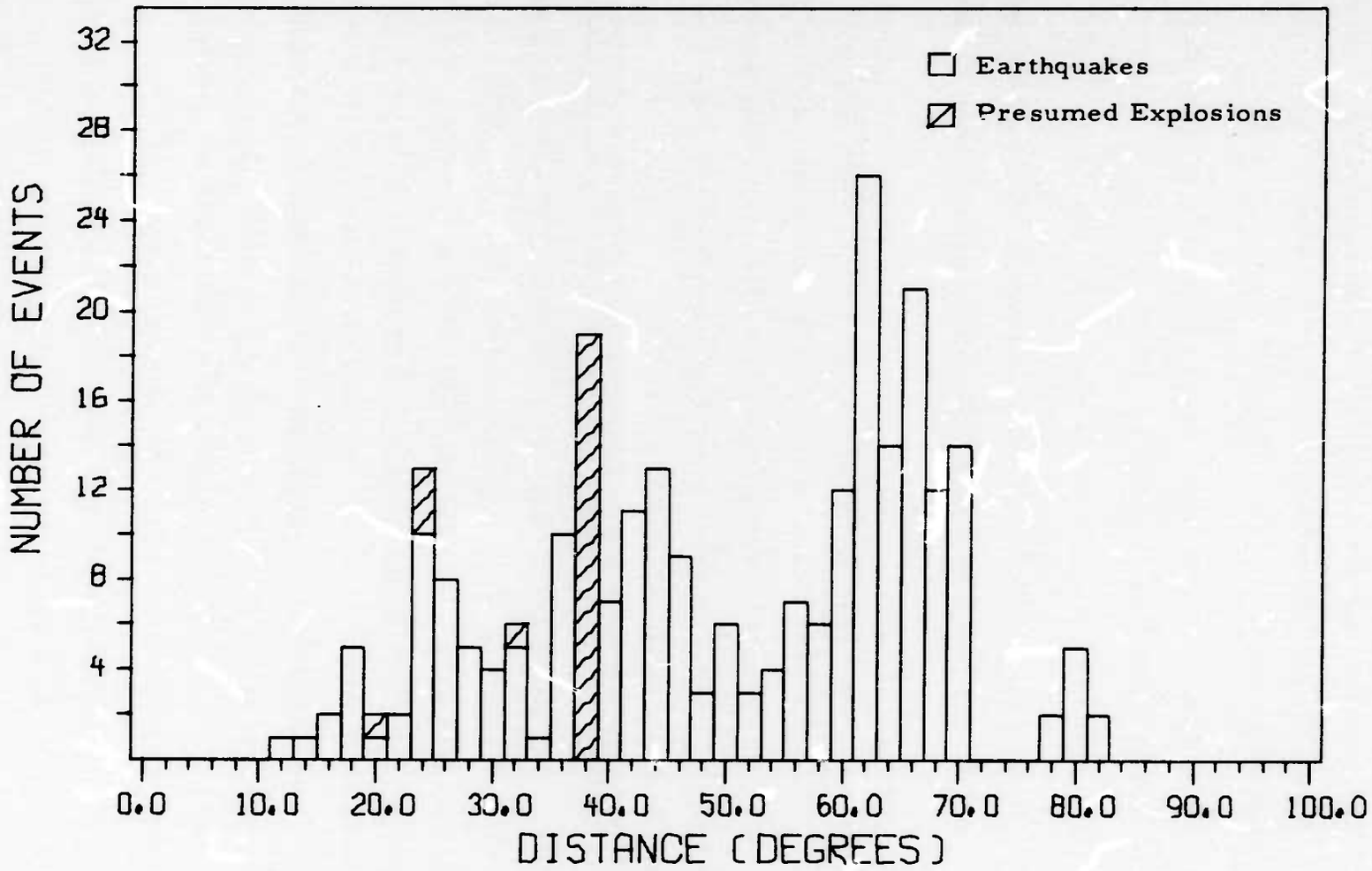

FIGURE I-3

DISTRIBUTION OF PROCESSED EVENTS AS A FUNCTION OF EPICENTRAL DISTANCE FROM NORSAR

- The Mediterranean area (Distance 15-30 degrees). Approximately 30 events from this region have been processed.
- Iran and Central Asia (Distance 35-50 degrees). The number of events is approximately 70.
- Kamchatka and the Kuriles Islands (Distance 60-70 degrees). Approximately 100 events from this region are included in our data base.

A total of nine discriminants have been evaluated in this report. Five of these are based on short period data only; the remaining four combine short and long period information. The discriminants are briefly described as follows:

1. P30 Mean Square

This discriminant, which is a measure of event complexity, is computed by crosscorrelating 4 seconds of the waveform (beginning a few points before P-wave onset) with the next 30 seconds of the waveform and with the noise preceding the signal. A mean square, weighted by the lag, is then computed from the correlations over both 30 seconds of the noise and 30 seconds of the signal. The noise mean square is subtracted from the signal mean square to obtain the discriminant used (Texas Instruments Incorporated, 1971).

2. Autocorrelation Mean Square

This discriminant is also a measure of complexity. The autocorrelations of a 30-second noise gate and of a 30-second signal gate are computed and a weighted mean square then derived from these correlations for the noise and signal. The discriminant is derived from the signal mean square minus the noise mean.

3. Envelope Difference

This discriminant is also derived from the P30 correlation by computing the mean-square difference between the envelope correlation and a fixed decaying exponential, the decay rate of which is the average rate for an ensemble of 16 explosions recorded at LASA. As with the first two statistics, envelope difference is a measure of complexity.

4. Dominant Period

This discriminant is computed by finding the cycle in the waveform with the maximum absolute amplitude; the dominant period is the duration of this cycle in seconds. This parameter can be estimated with some confidence, even for events with a relatively low signal-to-noise ratio. The dominant period discriminant is a rough measure of spectral energy distribution.

5. Spectral Ratio

This discriminant is derived from the signal power spectrum over a gate beginning just before the signal arrival. The power spectrum is smoothed over three frequency points, and the power in three bands is computed; Band 1: 0 - 0.55 Hz; Band 2: 0.55 - 1.5 Hz; Band 3: 1.5 - 5.0 Hz. These bands have been selected based on NORSAR data. Spectral ratios computed were Band 3 to Band 2 and Band 3 to Band 1, respectively.

6. M_s (Rayleigh) - m_b Discriminant

This discriminant compares the magnitude of the Rayleigh wave signal measured at NORSAR to the reported bodywave magnitude of each event. The detailed procedure of measuring M_s is described in Special Report No. 12 (1973).

7. M_s (Love) - m_b Discriminant

This discriminant compares the magnitude of the Love wave signal measured at NORSAR to the reported bodywave magnitude of each event.

8. AR/m_b Discriminant

The AR value is a measure of the Rayleigh wave energy of an event (Brune, Espinosa and Oliver (1963); Evernden (1969)). Our AR values have been normalized to a bodywave magnitude of 5.0 as described in Special Report No. 12 (1973).

9. AL/m_b Discriminant

The AL values are computed by the same method as described for AR, except that in this case, measurements are taken of the Love wave energy.

All the nine discriminants defined above are two-dimensional, in the sense that discriminant values are plotted against bodywave magnitudes (m_b) in order to obtain a good separation between earthquakes and presumed explosions. It is thus important to obtain an m_b estimate which is as reliable as possible for each event. We have chosen to use the m_b value quoted in the source bulletin (PDE, ISM, LASA, NORSAR) in almost all cases; the only exception is events for which the PDE m_b has been based upon near-field stations only. In those cases, we have used the NORSAR m_b values.

The first five discriminants defined above were applied to all events with SP detections at NORSAR; similarly, the last four were evaluated for all LP detections. Table I-3 summarizes the number of detected events; it is seen that about 90 percent of all reference events were detected on SP data, while about 70 percent had LP detections (Rayleigh waves, Love waves or both). The NORSAR LP detection capability is actually somewhat lower than these numbers indicate, since "mixed" events (i.e., events for which the LP signals have been buried in signals from a stronger event) were not included in our data base. It was found in Special Report No. 12 (1973) that about 20 percent of the events originally selected for that report were of this type.

TABLE I-3

DETECTION PERFORMANCE OF THE NORSAR SP AND LP ARRAYS FOR THE REFERENCE EVENT SET

	Earthquakes	Presumed Explosions
Number of reference events	233	24
Number of events detected on SP	208 (89%)	24 (100%)
Number of events detected on LP	164 (70%)	20 (83%)
Number of events detected on both SP and LP	160 (68%)	20 (83%)

SECTION II
NORSAR DISCRIMINATION RESULTS

A. INTRODUCTION

This section presents the results achieved by applying the nine discriminants defined in Section I to NORSAR data. The performance of each individual criterion is described in Subsection II-B, while combined criteria are evaluated in Subsection II-C.

A method for measuring the separation achieved by single or multiple discriminants was introduced in Special Report No. 11, 1973, and will also be applied here. Basically, the method consists of finding the best linear separation between two point sets in a plane, in the following way (Figure II-1):

1. For any given straight line, the distances from the line are computed for all points corresponding to events in the earthquake and presumed explosion populations.

2. The two sets of real numbers thus obtained are considered as sampled from two Gaussian populations; one $N(\mu_1, \sigma_1)$ (earthquakes) and one $N(\mu_2, \sigma_2)$ (presumed explosions).

3. The straight line that gives two Gaussian populations with the best separation is chosen and the measure of separation is defined as the corresponding probability of correct classification.

There is no unique method of computing the separation of two Gaussian distributions with unequal variances. We chose under 3. above to measure the separation by computing the worst case probability of

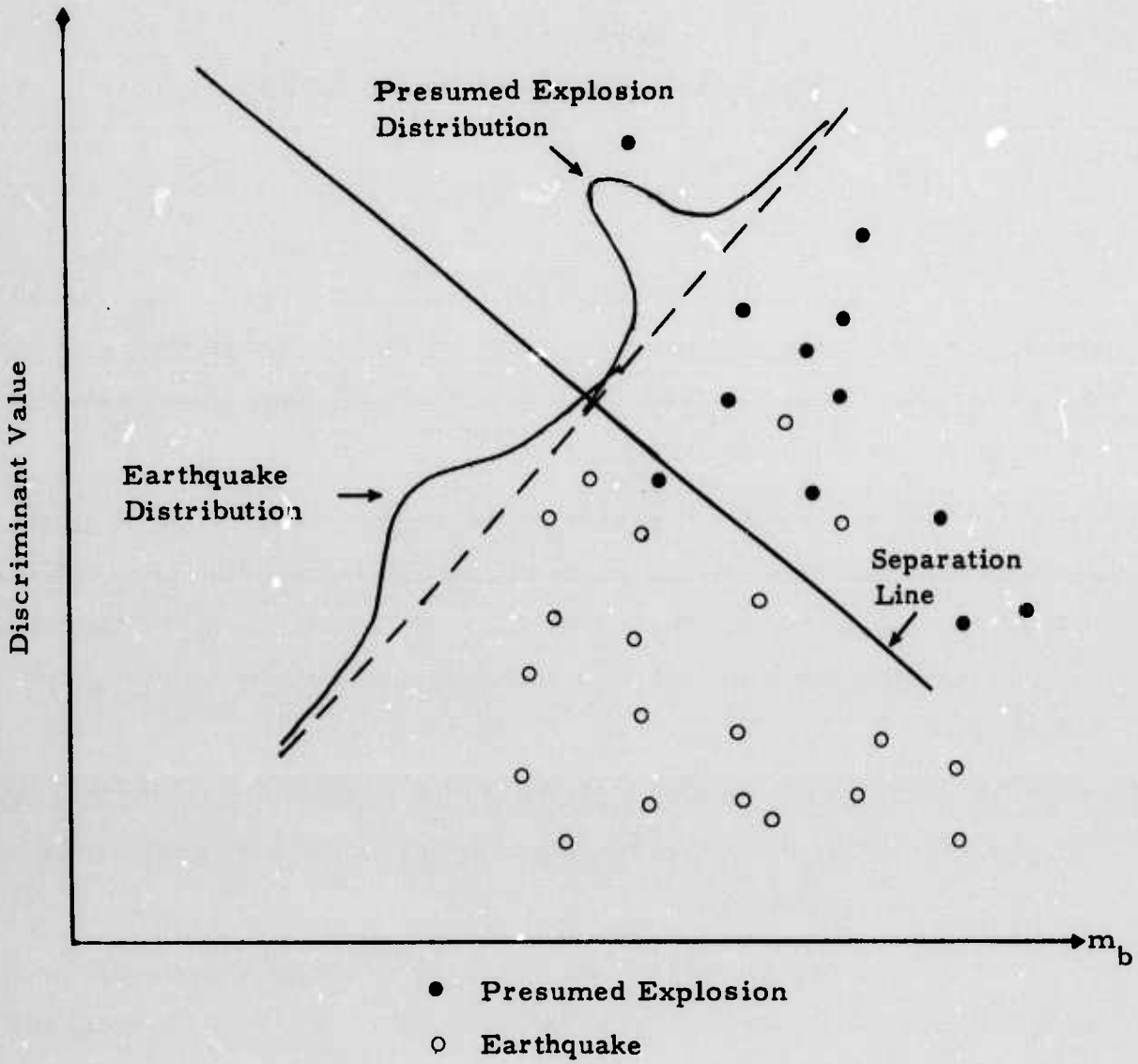

FIGURE II-1

ILLUSTRATION OF A METHOD TO MEASURE THE SEPARATION BETWEEN TWO POINT SETS IN A PLANE

misclassification, applying the well-known minimax principle (van Trees, 1968). The minimax separation threshold between the two populations is given as

$$T = \frac{\mu_2 \sigma_1 + \mu_1 \sigma_2}{\sigma_1 + \sigma_2}$$

and the associated probability of error is

$$P(\text{miss}) = P(\text{false alarm}) = \Phi\left(-\frac{|\mu_1 - \mu_2|}{\sigma_1 + \sigma_2}\right)$$

where Φ is the standard cumulative Gaussian distribution function.

Thus it is seen that for the above threshold T , the conditional probabilities of correctly identifying an earthquake and correctly identifying a presumed explosion are identical, and therefore provide a well-defined measure of the separation of the two populations.

The method of measuring separation described above may be easily adapted to multivariate discriminants. In fact, since the method reduces a two-dimensional discriminant to two sets of real numbers, it can be applied successively to reduce any given array of discriminant values to the one-dimensional case.

B. PERFORMANCE OF INDIVIDUAL DISCRIMINANTS

Individual discriminant values for each of the discriminants defined in Section I are plotted as a function of bodywave magnitude in Figures II-2 through II-11. Earthquakes are represented by a cross, while presumed explosions are indicated by an asterisk. All short period discriminants have been evaluated on the adjusted-delay array beam. The complete set of discriminant values corresponding to these plots are listed in Appendix A.

The "best separation line" as defined in Subsection II-A between the earthquake and presumed explosion populations has been drawn for

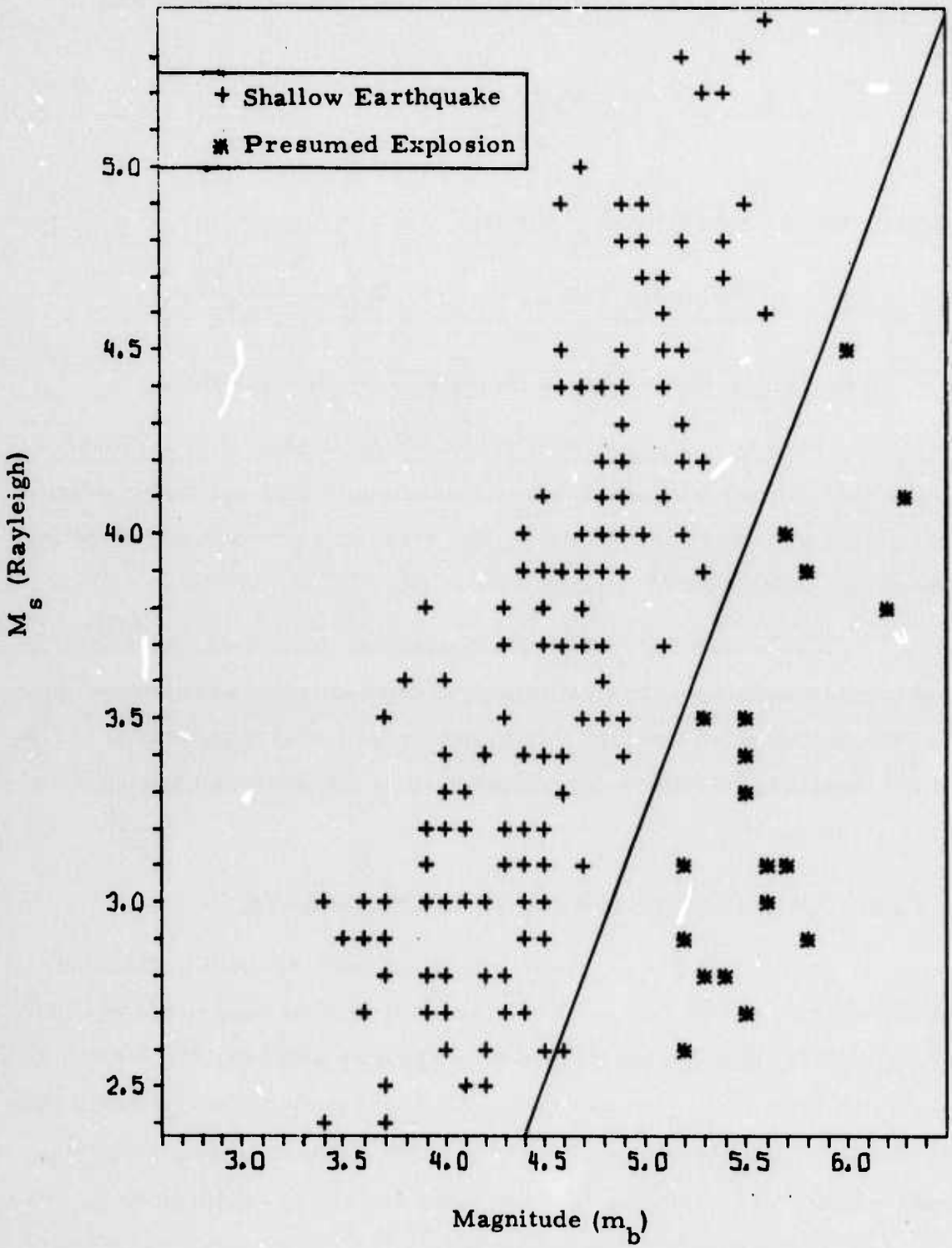

FIGURE II-2

M_s (RAYLEIGH) VERSUS m_b DISCRIMINANT

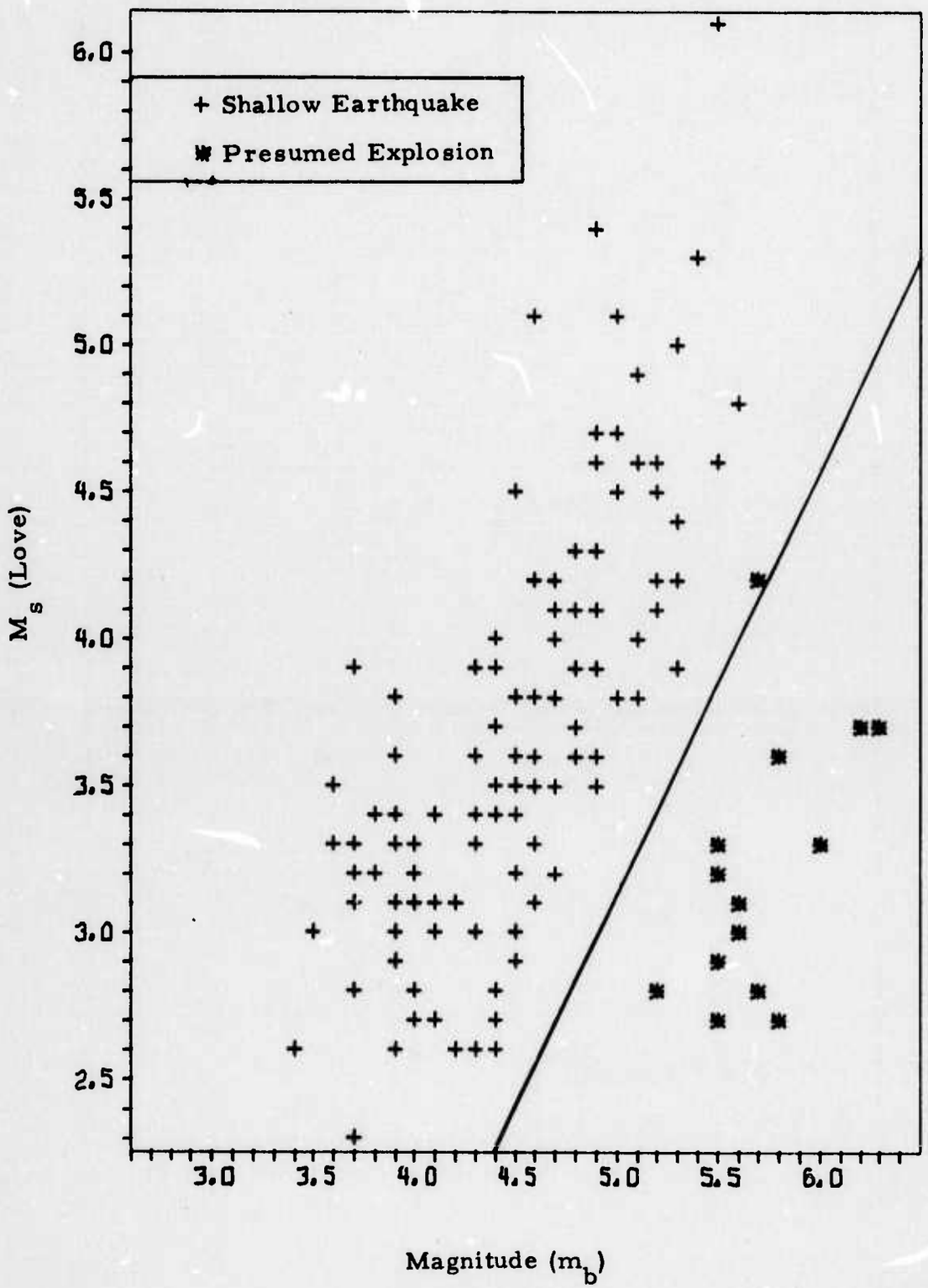

FIGURE II-3

M_s (LOVE) VERSUS m_b DISCRIMINANT

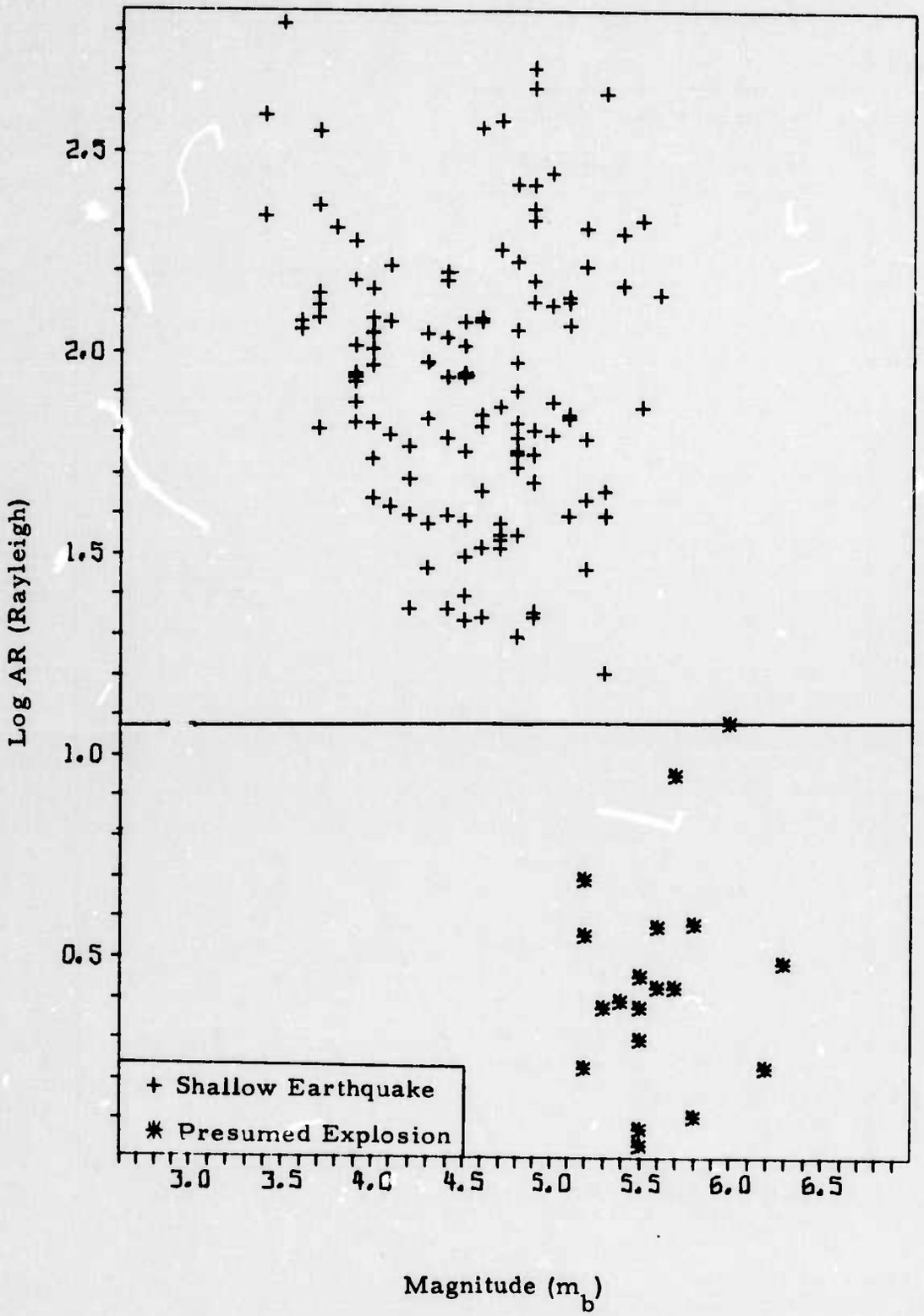

FIGURE II-4

AR (RAYLEIGH) VERSUS m_b DISCRIMINANT

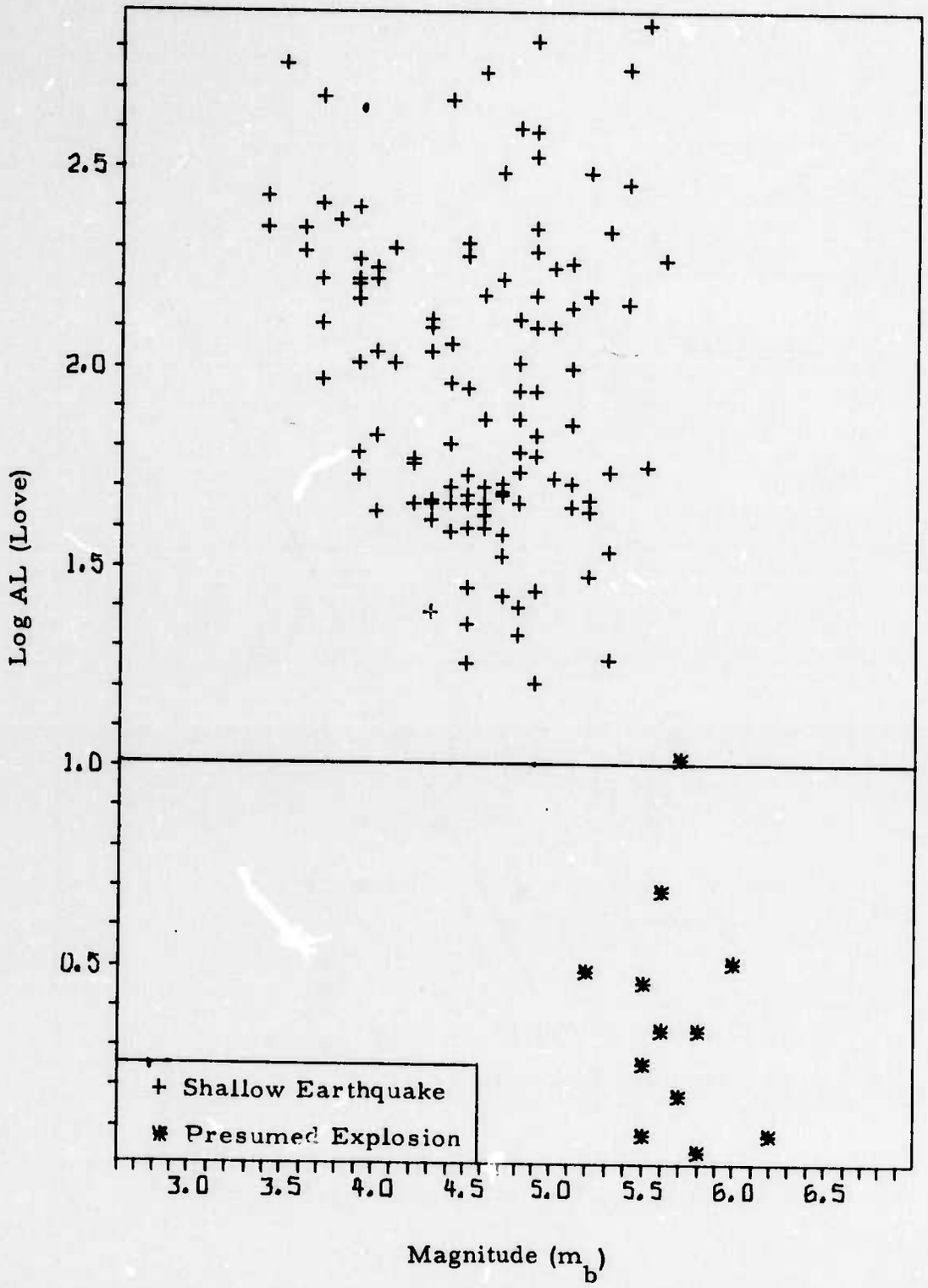

FIGURE II-5

AL (LOVE) VERSUS m_b DISCRIMINANT

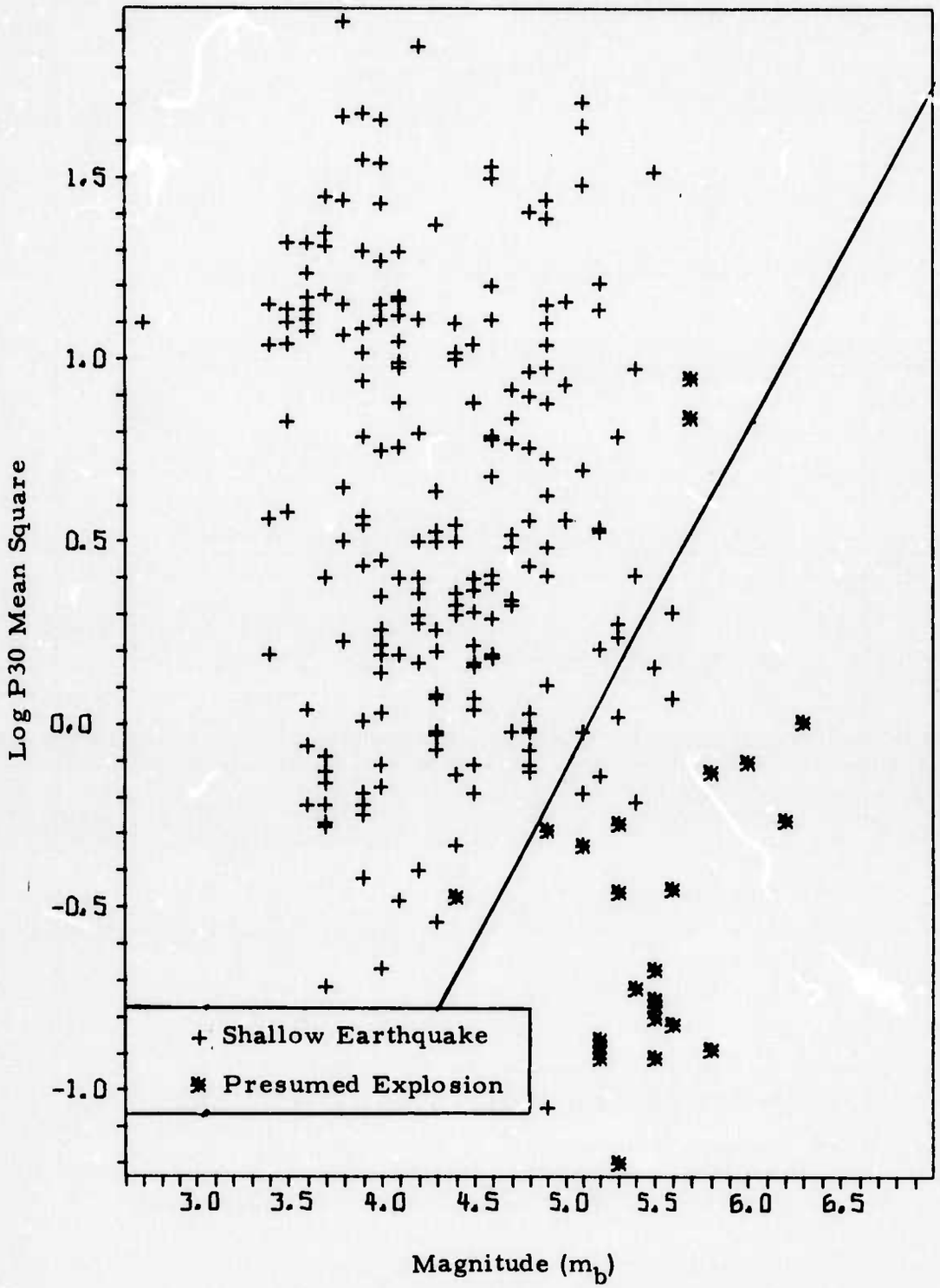

FIGURE II-6

P30 VERSUS m_b DISCRIMINANT

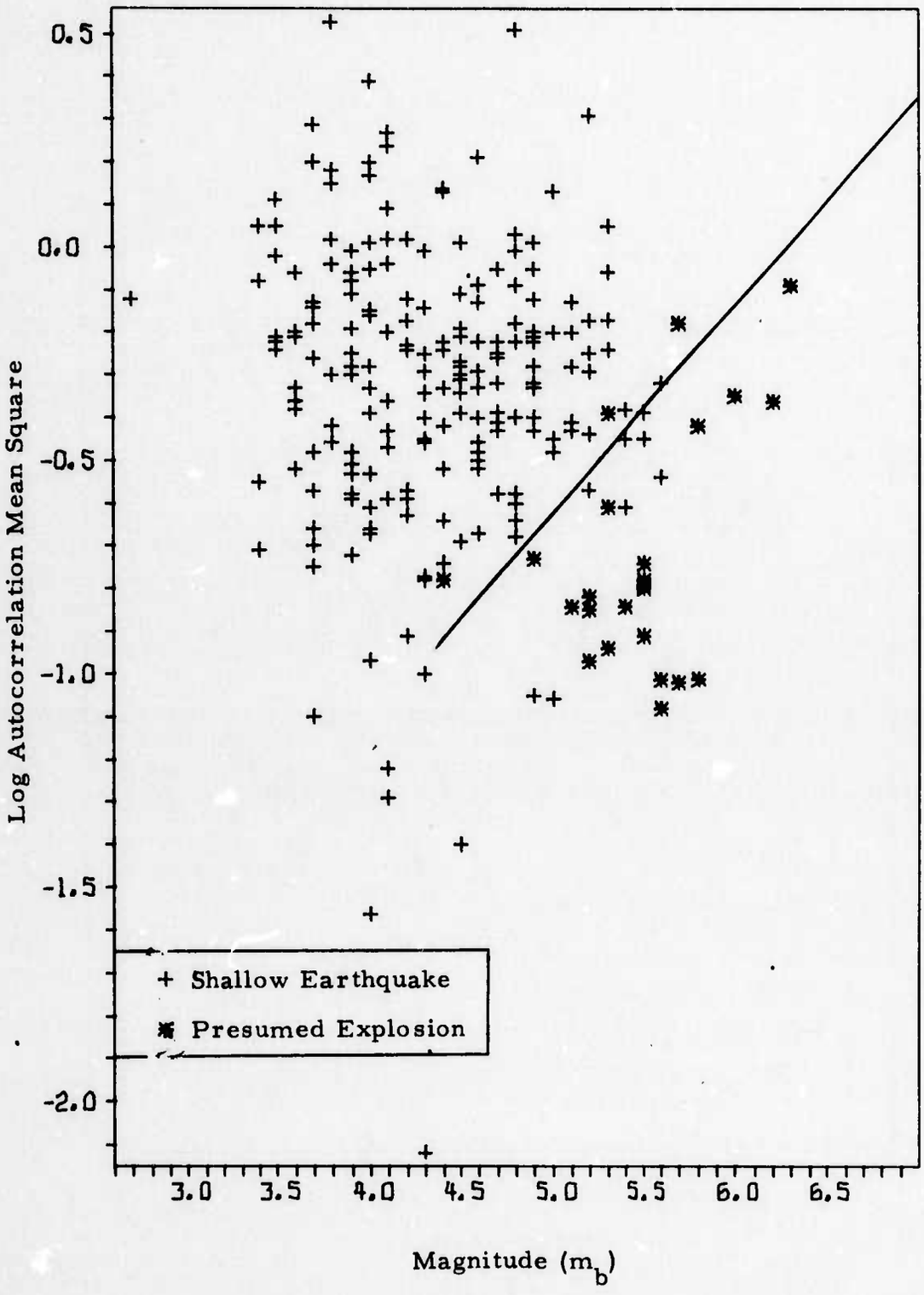

FIGURE II-7

AUTOCORRELATION VERSUS m_b DISCRIMINANT

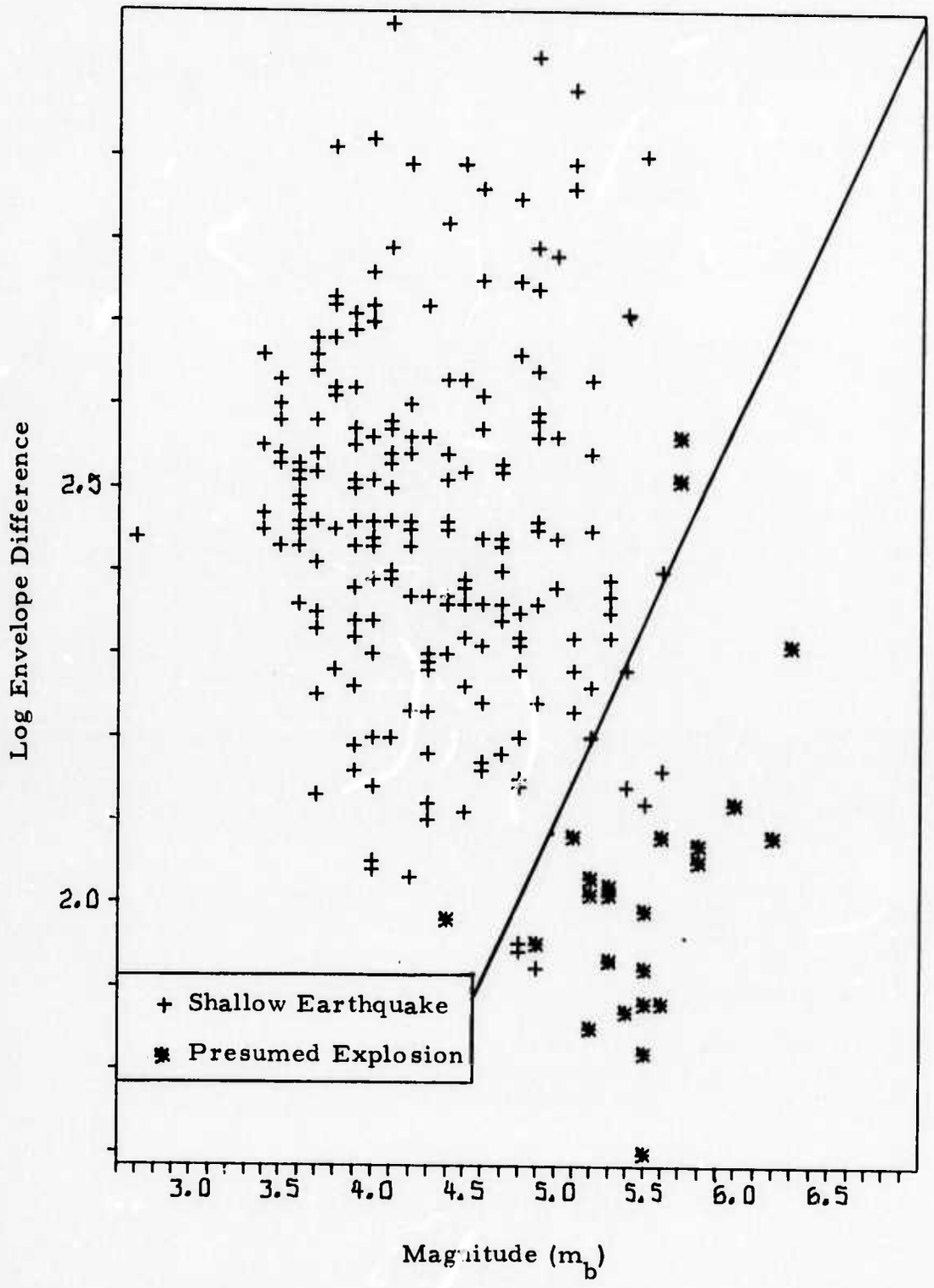

FIGURE II-8

ENVELOPE DIFFERENCE VERSUS m_b DISCRIMINANT

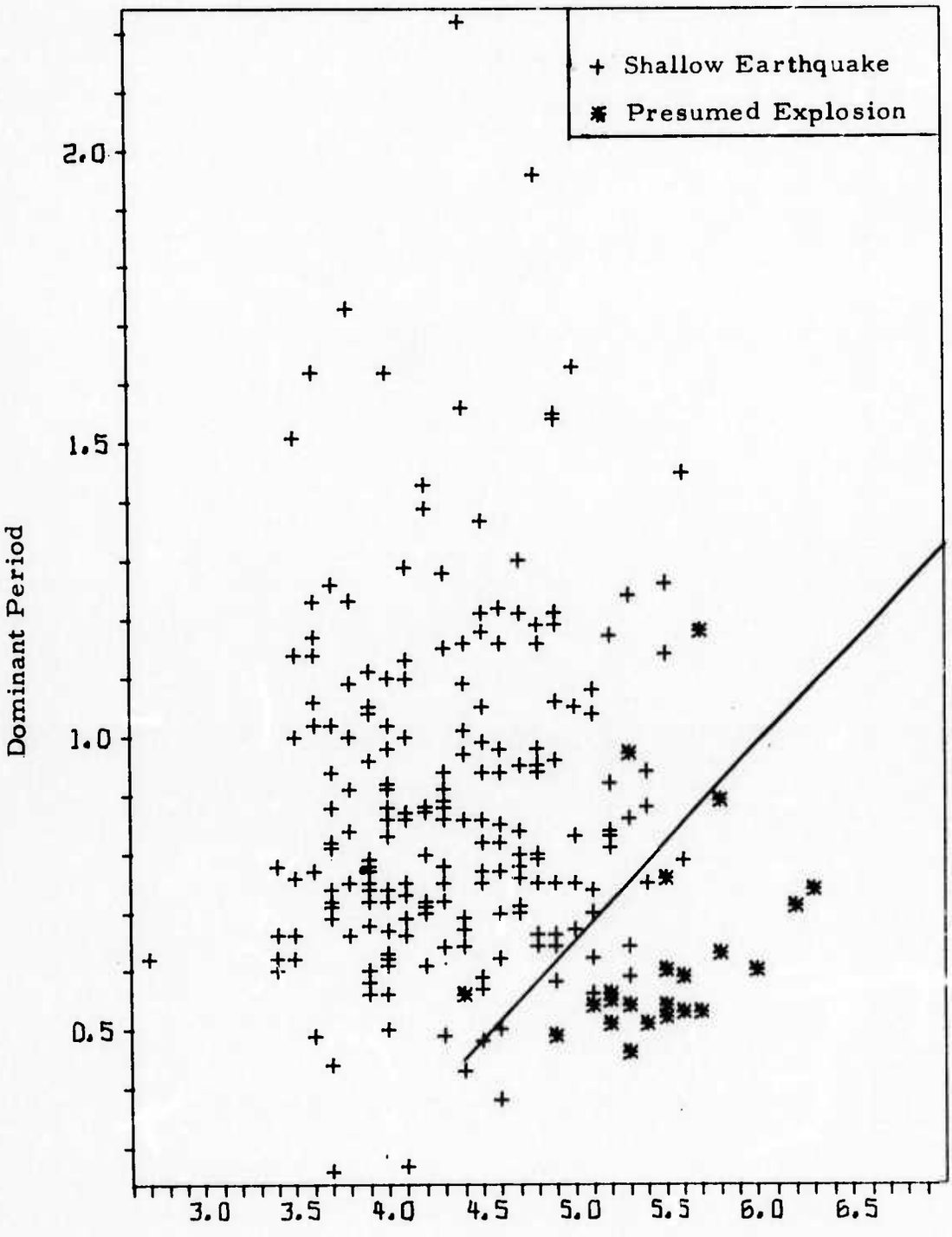

FIGURE II-9

DOMINANT PERIOD VERSUS m_b DISCRIMINANT

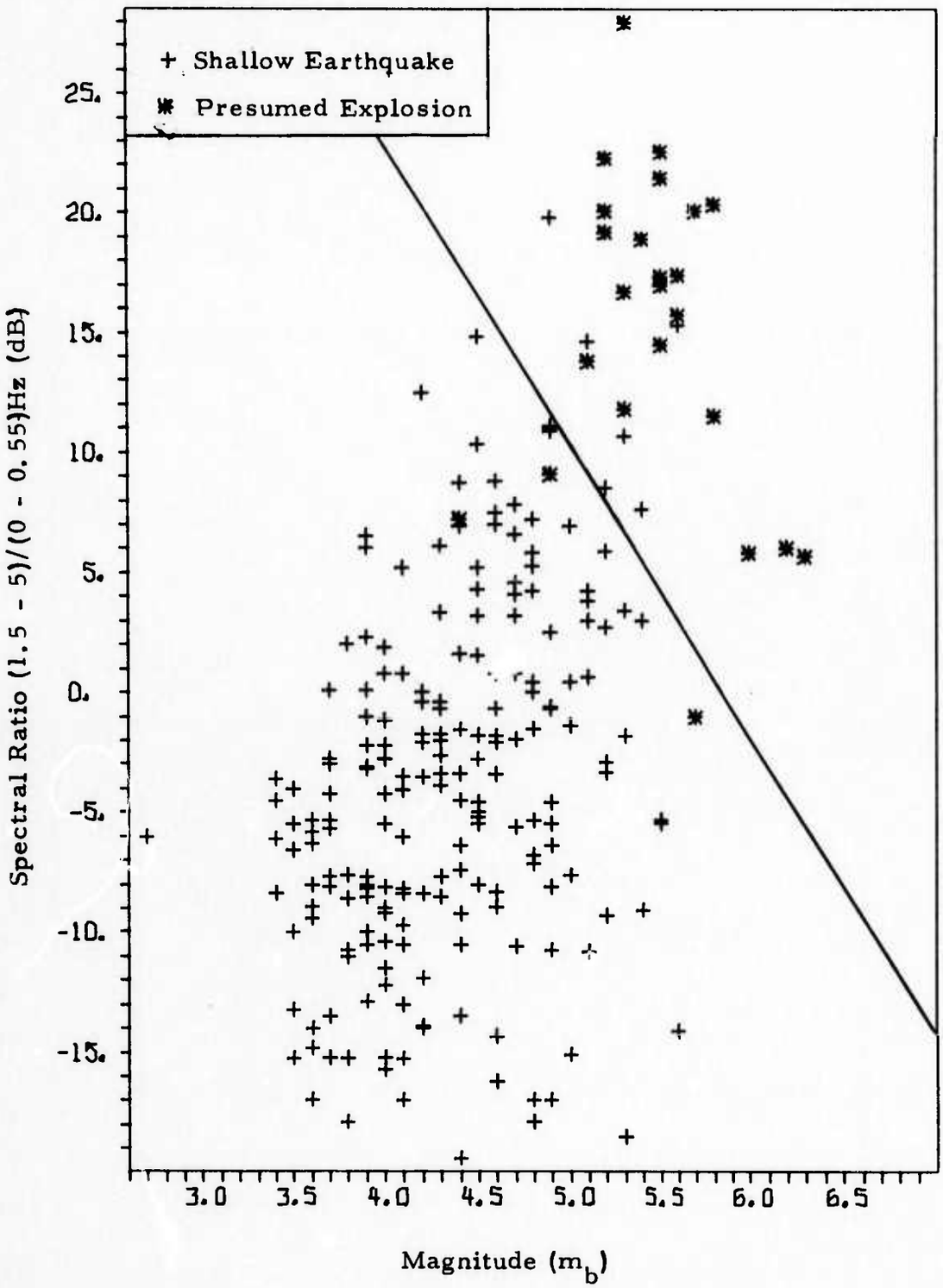

FIGURE II-10

SPECTRAL RATIO (1.5 - 5)/(0 - 0.55) Hz

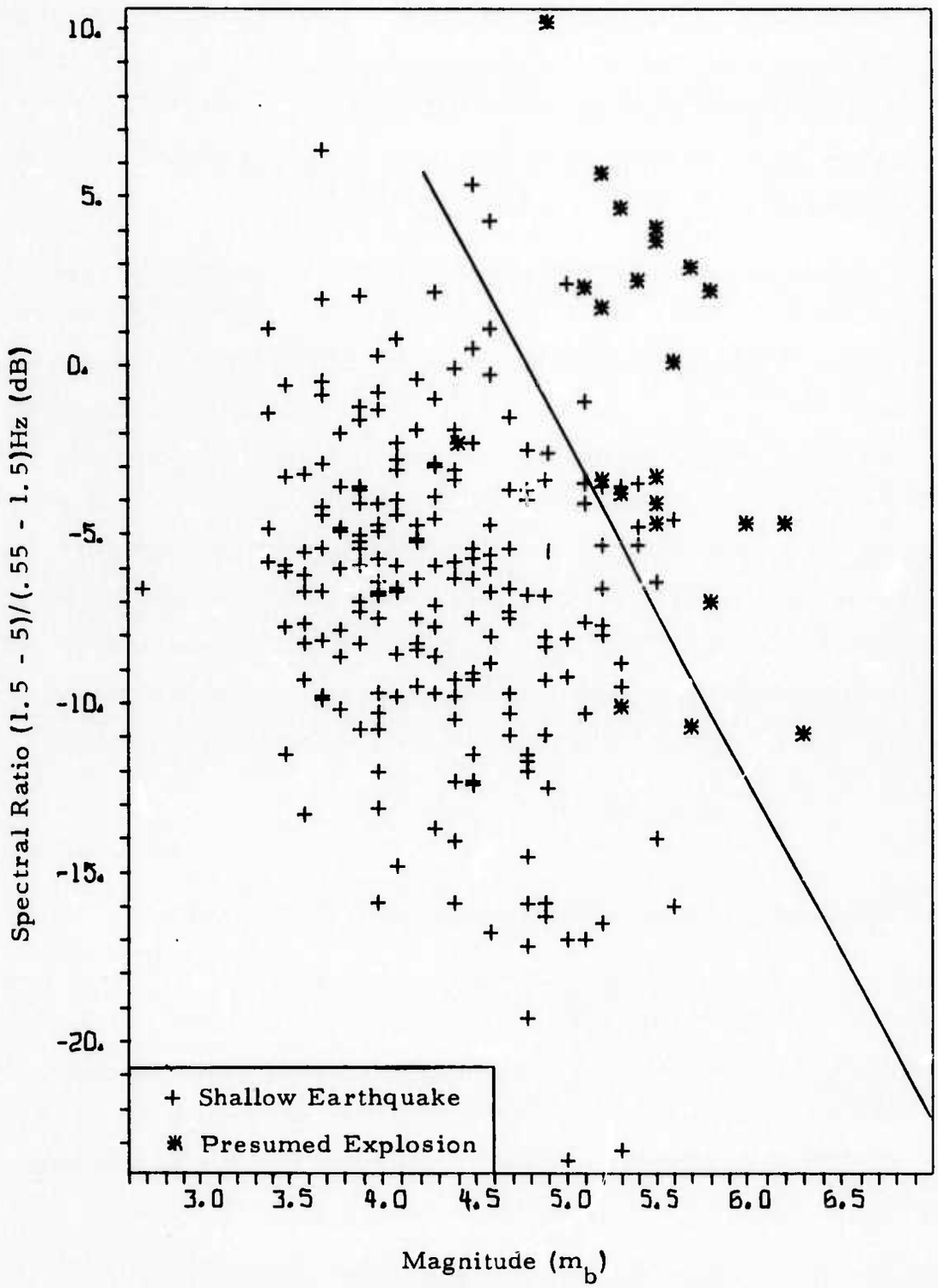

FIGURE II-11

SPECTRAL RATIO (1.5 - 5)/(.55 - 1.5) Hz

each discriminant plot. Note that this line has been found on the basis of all events with $m_b \geq 4.4$; this is because all our presumed explosions are of at least this magnitude. For the AR and AL discriminants (Figures II-10 and II-11), the separation line has been restricted to be parallell with the m_b axis, since these two discriminants are already normalized with respect to bodywave magnitude.

For each discriminant, the distance from the best separation line is a measure of how well this discriminant has been able to classify a given event. These distances are listed in Tables II-1 and II-2 for presumed explosions and earthquakes, respectively. In order to make the numbers compatible between discriminants, all distances were normalized by dividing by the standard deviation in the respective earthquake population. A positive distance means that the event lies on the "correct" side of the separation line, while a negative distance indicates misclassification. Figure II-12 illustrates how this distance relates to the probability distribution of the earthquake population, which is assumed to be Gaussian (μ_1, σ_1). In fact, the probability of an earthquake exceeding the distance D from the separation threshold is

$$P(\text{exceed } D) = 1 - \Phi\left(\frac{D + \mu_1}{\sigma_1}\right)$$

where Φ is the standard cumulative Gaussian distribution function.

It is seen from the discriminant plots and confirmed by Tables II-1 and II-2 that the four combined SP-LP discriminants achieve essentially complete separation between the earthquake and presumed explosion populations. In contrast, the short period discriminants do not perform nearly as well, and all of them misclassify several earthquakes and several presumed explosions.

TABLE II-1

PERFORMANCE OF INDIVIDUAL DISCRIMINANTS FOR PRESUMED EXPLOSIONS.
NUMBERS REPRESENT NORMALIZED DISTANCE FROM SEPARATION LINE;
NEGATIVE SIGN INDICATES MISCLASSIFICATION

EVENT DESIGNATION	DEPTH	MB	MS(R) -MB	MS(L) -MB	AR -MB	AL -MB	P30 -MB	AUTO -MB	ENVD -MB	PER -MB	B3/B1 -MB	B3/B2 -MB
EKZ/204/01N	0	6.3	2.2	2.8	1.7	-	2.0	0.4	1.5	1.0	1.2	0.8
EKZ/307/01N	0	6.2	2.6	2.5	2.4	2.3	2.3	1.1	2.2	1.0	1.1	1.6
KAZ/356/06N	0	6.0	0.4	2.7	-0.0	1.2	1.6	0.7	1.7	1.2	0.8	1.3
EKZ/364/06N	0	5.8	1.1	1.5	1.4	1.6	2.6	2.5	1.6	0.9	2.1	2.1
SWR/277/08N	0	5.8	3.3	3.4	2.7	2.4	1.4	0.6	1.5	0.1	1.2	0.6
WKZ/233/02N	0	5.7	2.5	2.9	1.8	2.0	-0.5	-0.3	-0.2	-0.9	-0.3	-0.2
EKZ/345/04N	0	5.7	0.6	-0.1	0.3	-0.1	-0.7	2.4	-0.3	1.1	2.0	2.0
EKZ/294/06N	0	5.6	2.2	2.0	1.8	1.6	1.6	2.2	1.8	0.8	1.5	1.4
EKZ/047/05N	0	5.6	2.4	2.2	1.4	0.8	2.2	2.4	1.1	1.0	1.4	1.4
KAZ/157/04N	0	5.5	1.1	2.5	2.2	1.8	1.8	1.3	1.3	0.8	1.8	1.9
KAZ/170/04N	0	5.5	1.5	2.1	2.9	2.3	1.9	1.7	1.5	0.9	2.0	1.9
EKZ/333/06N	0	5.5	1.3	1.4	1.7	1.3	1.9	1.3	1.7	0.7	1.4	0.6
EKZ/041/05N	0	5.5	2.8	-	2.8	-	2.2	1.2	1.9	0.2	1.1	0.5
KAZ/070/04N	0	5.5	1.5	1.2	2.0	1.8	2.0	1.4	2.3	0.7	1.4	0.7
KAZ/282/06N	0	5.4	2.3	-	1.9	-	1.7	1.3	1.5	0.8	1.4	1.5
URA/191/16N	0	5.3	-	-	-	-	0.7	0.4	0.9	0.9	2.3	1.7
EKZ/227/01N	0	5.3	0.4	-	-	-	1.1	-0.3	1.1	-0.7	0.6	-0.7
EKZ/240/03N	0	5.3	1.9	-	2.0	-	2.3	1.5	0.8	0.6	1.1	0.3
KAZ/145/04N	0	5.2	2.1	-	2.4	-	1.7	1.0	0.7	0.6	1.5	1.7
EKZ/088/04N	0	5.2	1.4	1.4	1.5	1.2	1.6	0.9	1.2	0.5	1.2	0.2
EKZ/229/03N	0	5.2	1.0	-	1.1	-	1.6	1.4	0.6	0.5	1.3	1.0
EKZ/246/08N	0	5.1	-	-	-	-	0.5	0.8	0.3	0.4	0.5	1.0
EKZ/349/07N	0	4.9	-	-	-	-	0.1	0.2	0.4	0.4	-0.2	1.9
EKZ/188/01N	0	4.4	-	-	-	-	-0.5	-0.5	-0.6	-0.3	-1.1	-0.9

TABLE II-2

PERFORMANCE OF INDIVIDUAL DISCRIMINANTS FOR EARTHQUAKES OF $m_b \geq 4.4$
NUMBERS REPRESENT NORMALIZED DISTANCE FROM SEPARATION LINE
NEGATIVE SIGN INDICATES MISCLASSIFICATION
(PAGE 1 OF 4)

EVENT DESIGNATION	DEPTH	MB	MS(R) −MB	MS(L) −MB	AR −MB	AL −MB	P3D −MB	AUTO −MB	ENVD −MB	PER −MB	P3/P1 −MB	P3/P2 −MB
KUR/213/02N	20	5.6	2.7	-	-	-	-0.7	-0.7	-0.9	-0.2	-1.3	-0.7
UAR/180/09N	15	5.6	1.0	1.6	3.0	3.2	-0.3	0.0	-0.0	1.3	1.8	1.2
PAK/179/06N	12	5.5	2.0	1.5	2.2	1.9	-0.3	-0.0	-0.8	1.3	1.0	1.0
TIB/204/16N	33	5.5	2.8	4.6	3.5	4.6	2.0	-0.2	1.8	1.0	1.0	-0.2
TIB/123/00N	16	5.4	2.9	-	3.1	2.9	-0.8	-0.1	-0.6	-0.1	0.2	-0.3
IR1/164/13N	33	5.4	1.8	3.3	3.4	3.7	0.2	-0.6	-0.1	0.3	-0.3	-0.5
IRA/184/12N	31	5.4	2.1	3.3	-	4.4	1.2	0.2	1.4	0.5	1.5	-0.2
SIB/013/17N	33	5.3	3.2	2.9	4.4	3.4	1.1	1.4	0.3	-0.5	0.9	0.6
TIB/075/06N	33	5.3	0.4	0.6	0.4	0.7	-0.2	1.0	0.2	-0.3	-0.4	-0.3
IRA/166/04N	33	5.3	0.4	1.7	1.6	1.9	0.1	0.8	0.4	0.2	0.3	0.5
KAM/199/08N	33	5.3	1.1	1.3	1.5	1.4	0.2	1.7	0.4	1.5	2.6	2.8
KIR/170/17N	33	5.2	3.7	-	3.5	3.7	0.8	0.8	0.8	0.3	0.2	-0.2
SIN/002/10N	33	5.2	1.4	1.6	1.1	1.2	0.8	0.3	0.2	0.2	-0.1	0.3
KUR/077/07N	33	5.2	2.0	1.3	2.0	1.6	0.2	1.2	-0.0	0.2	0.5	0.5
TAD/077/09N	33	5.2	2.7	2.2	3.2	3.0	1.9	-0.1	1.1	0.4	1.1	0.5
KUR/193/06N	33	5.2	0.9	-	1.6	-	1.8	2.7	1.4	0.6	1.8	0.1
TIB/198/02N	33	5.2	1.6	2.4	-	1.7	-0.3	0.9	-0.0	1.4	1.2	1.9
KAM/166/14N	55	5.1	2.8	-	2.1	2.2	1.2	1.5	0.5	1.2	0.5	1.1
IRA/014/22N	33	5.1	0.6	1.4	1.5	1.8	-0.3	0.5	0.2	0.2	0.6	0.1
IRA/165/00N	27	5.1	1.5	2.7	3.0	3.2	0.0	0.5	0.4	-0.2	0.5	-0.4
HIN/179/15N	53	5.1	2.1	1.0	3.0	1.6	2.6	0.5	2.4	-0.4	-0.6	-0.0
KUR/209/00N	33	5.1	2.5	2.7	2.8	2.5	3.0	1.2	2.5	0.0	0.9	0.6
RYU/209/16N	33	5.1	2.3	3.3	2.2	2.9	2.8	1.0	2.8	1.1	2.1	2.2
SIN/241/15N	33	5.0	-	-	-	-	1.2	-1.4	0.9	0.1	0.3	-0.8
KUR/055/10N	33	5.0	3.5	2.8	3.9	2.8	1.2	0.5	0.9	0.3	1.0	1.1

TABLE II-2

PERFORMANCE OF INDIVIDUAL DISCRIMINANTS FOR EARTHQUAKES OF $m_b \geq 4.4$
NUMBERS REPRESENT NORMALIZED DISTANCE FROM SEPARATION LINE
NEGATIVE SIGN INDICATES MISCLASSIFICATION
(PAGE 2 OF 4)

EVENT DESIGNATION	DEPTH	MB	MS(R) -MB	MS(L) -MB	AR -MB	AL -MB	P30 -MB	AUTO -MB	ENVD -MB	PEP -MB	B3/B1 -MB	B3/B2 -MB
RYU/155/02N	33	5.0	3.1	3.2	2.3	1.8	1.2	1.4	1.1	1.2	1.9	2.3
TAI/178/08N	33	5.0	3.3	4.0	2.9	3.1	2.2	2.5	2.3	3.0	2.6	3.4
IRA/185/02N	38	5.0	1.6	1.3	2.0	-	1.8	0.6	1.5	0.5	1.2	0.9
TUR/161/09N	33	4.9	2.5	-	-	-	2.1	1.5	2.0	1.8	1.3	1.8
KIR/166/23N	33	4.9	2.1	-	0.9	1.1	2.8	1.3	3.3	0.1	0.1	0.1
KUR/190/16N	46	4.9	3.8	-	3.5	3.4	1.2	1.5	1.3	0.4	0.9	0.6
CRE/012/13N	33	4.9	2.3	1.9	3.8	3.0	0.6	1.1	0.6	0.1	-0.9	0.2
IRA/018/21N	33	4.9	0.6	1.8	1.7	2.4	1.5	1.2	1.4	-0.1	0.0	-0.8
SIN/042/05N	33	4.9	2.3	2.7	1.9	2.1	1.6	1.1	1.4	1.3	1.8	1.4
KUR/057/05N	33	4.9	0.8	1.0	0.8	0.6	-1.4	-1.2	-0.5	0.1	0.0	0.4
LOM/058/10N	33	4.9	1.7	1.2	3.1	2.8	2.4	1.8	1.8	2.8	3.0	2.5
TAI/160/10N	33	4.9	2.9	3.3	2.1	2.0	1.1	1.5	1.0	1.7	1.7	1.6
CRE/161/07N	33	4.9	1.9	2.2	3.6	3.2	2.2	0.9	1.8	1.0	1.3	0.9
GRE/167/00N	26	4.9	2.3	2.7	4.5	3.8	2.3	2.0	2.3	1.8	2.0	1.2
TAI/182/18N	33	4.9	3.6	5.0	3.0	4.0	1.9	0.8	1.7	2.8	1.9	1.1
TUR/198/02N	33	4.9	2.7	3.5	4.6	4.6	2.8	2.2	2.5	1.8	2.3	2.4
TAD/147/00N	36	4.8	2.4	-	2.1	2.0	1.5	1.6	1.0	1.1	1.9	2.0
KUR/191/03N	36	4.8	3.0	-	2.5	2.2	0.5	0.2	-0.2	0.5	0.8	0.7
TUR/251/22N	33	4.8	3.0	-	3.8	4.0	2.2	2.5	2.2	4.2	3.2	2.6
KAM/003/06N	33	4.8	2.0	2.1	1.9	1.9	0.5	2.1	0.9	0.6	1.5	2.4
KAM/012/20N	33	4.8	2.6	3.0	2.8	2.8	3.0	1.1	2.5	0.7	0.9	0.7
DOD/020/02N	33	4.8	2.2	1.7	3.2	2.5	0.6	2.3	0.6	1.7	3.1	3.1
KAM/052/22N	33	4.8	1.5	-	1.9	-	0.3	0.4	-0.2	1.1	1.3	1.9
KUR/054/03N	41	4.8	2.2	3.0	2.0	2.4	0.6	0.3	0.5	0.2	0.6	0.6
PAK/157/11N	27	4.8	1.1	1.5	0.6	1.0	2.1	0.4	1.2	1.2	2.0	1.1

TABLE II-2

PERFORMANCE OF INDIVIDUAL DISCRIMINANTS FOR EARTHQUAKES OF $m_b \geq 4.4$
NUMBERS REPRESENT NORMALIZED DISTANCE FROM SEPARATION LINE
NEGATIVE SIGN INDICATES MISCLASSIFICATION
(PAGE 3 OF 4)

EVENT DESIGNATION	DEPTH	MB	MS(R) -MB	MS(L) -MB	AR -MB	AL -MB	P30 -MB	AUTO -MB	ENVD -MB	PER -MB	B3/B1 -MB	B3/B2 -MB
SZE/203/16N	33	4.8	2.6	2.5	2.3	2.0	1.9	4.0	2.9	1.8	1.3	1.9
KUR/211/21N	33	4.8	2.4	2.1	1.8	1.7	1.3	1.8	1.0	1.1	2.1	2.8
KAM/213/06N	33	4.8	1.3	1.5	1.3	0.9	0.4	0.5	0.4	0.2	0.7	0.4
NEC/156/10N	33	4.7	4.6	-	3.3	3.7	2.2	1.5	1.9	0.8	2.0	1.7
TAI/006/06N	33	4.7	2.5	3.1	1.3	1.4	1.6	2.4	1.4	0.9	1.1	1.8
KUR/049/18N	33	4.7	2.1	2.2	1.4	1.8	1.3	1.3	1.3	0.7	1.0	1.4
YUN/057/18N	33	4.7	2.3	2.6	1.3	1.5	0.7	1.1	0.7	0.5	0.8	0.4
KAM/078/18N	33	4.7	1.4	1.6	1.3	1.1	2.3	1.7	1.6	2.3	2.6	1.9
CAS/166/00N	47	4.7	1.8	1.0	2.2	1.7	1.3	0.6	0.7	0.5	0.6	1.2
HIN/177/07N	46	4.7	3.3	3.1	4.2	3.1	2.0	1.7	1.9	0.6	1.0	1.0
TIB/198/03N	33	4.7	2.1	2.8	-	1.8	1.6	1.8	1.5	1.2	1.4	0.8
TIB/204/21N	33	4.7	0.5	2.2	-	1.1	1.3	1.2	1.6	2.0	1.7	1.4
TUR/126/04N	23	4.6	3.6	-	-	-	2.8	2.0	3.2	2.1	3.3	3.1
CAS/135/04N	33	4.6	1.3	-	1.3	1.5	1.6	1.0	1.1	1.3	1.7	1.8
KUR/191/09N	33	4.6	1.5	-	-	-	1.2	0.5	0.9	-0.1	0.9	-0.4
KUR/001/16N	33	4.6	-	2.1	-	1.6	3.5	3.4	3.2	-0.4	3.1	0.4
TAI/004/12N	33	4.6	4.7	5.2	4.2	4.4	3.0	2.4	2.4	1.9	2.5	1.4
KAM/025/10N	33	4.6	-	-	-	-	1.2	1.1	0.8	0.8	1.9	1.3
KAM/042/21N	33	4.6	2.6	3.3	2.8	3.0	3.5	1.2	2.9	-0.4	1.8	1.4
IRA/068/21N	45	4.6	2.1	1.9	2.1	1.6	1.6	2.3	1.5	0.6	0.7	1.1
YUG/180/01N	33	4.6	-0.2	1.0	0.8	1.7	2.1	1.6	2.4	1.0	2.5	1.6
AFG/181/03N	53	4.6	2.6	2.5	2.2	2.2	2.3	1.1	2.2	0.3	0.8	0.1
IRA/184/14N	31	4.6	1.3	1.5	1.7	1.6	1.4	1.4	1.4	1.4	1.8	1.1
TAI/198/13N	33	4.6	3.9	3.3	2.9	1.8	2.2	1.7	1.8	0.9	1.5	1.2
BLS/210/19N	33	4.5	0.1	-	-	-	1.2	1.8	1.8	1.1	1.6	2.0

TABLE II-2

PERFORMANCE OF INDIVIDUAL DISCRIMINANTS FOR EARTHQUAKES OF $m_b \geq 4.4$
NUMBERS REPRESENT NORMALIZED DISTANCE FROM SEPARATION LINE
NEGATIVE SIGN INDICATES MISCLASSIFICATION
(PAGE 4 OF 4)

EVENT DESIGNATION	DEPTH	MB	MS(R) -MB	MS(L) -MB	AR -MB	AL -MB	P30 -MB	AUTO -MB	ENVD -MB	PEP -MB	B3/B1 -MB	B3/B2 -MB
KAM/003/19N	33	4.5	-	2.2	-	1.7	1.5	2.5	1.7	0.9	1.9	2.4
KUR/005/02N	33	4.5	1.8	1.6	1.2	1.2	1.4	-1.7	0.8	-0.0	1.2	-0.4
TAD/005/12N	33	4.5	0.9	0.9	0.8	0.9	1.1	2.2	2.6	1.5	2.6	1.5
YUN/034/07N	33	4.5	3.3	4.3	2.8	3.3	1.8	2.0	1.6	1.4	2.0	1.7
GRE/044/13N	33	4.5	1.4	2.8	2.5	3.2	2.8	1.7	3.5	1.0	1.4	2.0
GRE/047/00N	33	4.5	0.7	2.0	1.5	2.4	2.6	2.2	3.5	0.8	0.6	1.4
BAI/058/22N	33	4.5	1.2	1.1	0.9	0.9	0.8	1.9	1.6	0.3	0.2	0.4
KUR/063/23N	33	4.5	2.7	2.2	2.4	1.7	1.4	1.9	2.2	2.1	2.2	0.9
SIN/064/04N	33	4.5	2.9	2.4	2.4	1.9	2.6	0.6	1.8	2.2	2.3	1.4
CHI/066/23N	33	4.5	-	-	-	-	-	-	-	-	-	-
PAK/162/11N	33	4.5	2.7	2.8	2.7	-	1.7	1.6	1.8	0.3	1.3	0.9
KU2/171/18N	33	4.5	2.5	2.2	1.9	1.5	1.6	2.9	1.7	1.7	2.2	2.5
KAM/199/20N	33	4.5	-	1.1	-	0.7	0.9	1.8	1.4	2.7	2.3	2.5
TUR/143/01N	33	4.4	3.4	-	-	-	2.1	1.6	2.2	2.2	1.7	1.6
KAM/004/10N	33	4.4	-	-	-	-	0.7	2.3	1.9	0.7	2.2	1.0
TUR/022/17N	33	4.4	0.6	0.6	-	-	3.1	0.9	2.5	1.9	3.0	2.7
ECS/028/04N	33	4.4	3.4	3.5	2.4	2.4	3.0	3.5	2.5	5.4	3.9	2.9
KIR/028/20N	33	4.4	1.0	2.3	0.8	1.5	1.0	1.6	1.9	0.6	1.1	1.2
ITA/035/09N	33	4.4	2.1	3.3	3.2	4.2	3.0	2.2	2.8	1.6	2.5	2.2
LOM/058/17N	33	4.4	1.0	0.8	1.5	1.7	1.9	1.9	2.4	1.7	2.6	2.2
AFG/059/18N	33	4.4	3.2	2.3	3.1	2.1	1.9	1.3	1.7	-0.1	0.9	0.7
YUG/063/21N	33	4.4	2.1	2.9	-	-	1.8	1.3	2.2	1.2	2.3	1.7
NEJ/157/19N	33	4.4	1.3	1.0	2.0	1.8	2.2	3.4	3.4	3.4	3.3	3.2
KAM/186/13N	33	4.4	1.7	-	-	-	0.7	0.6	1.7	0.7	2.0	1.2
TUR/206/10N	33	4.4	1.5	2.5	2.7	2.7	1.8	0.6	1.9	1.6	2.8	2.4

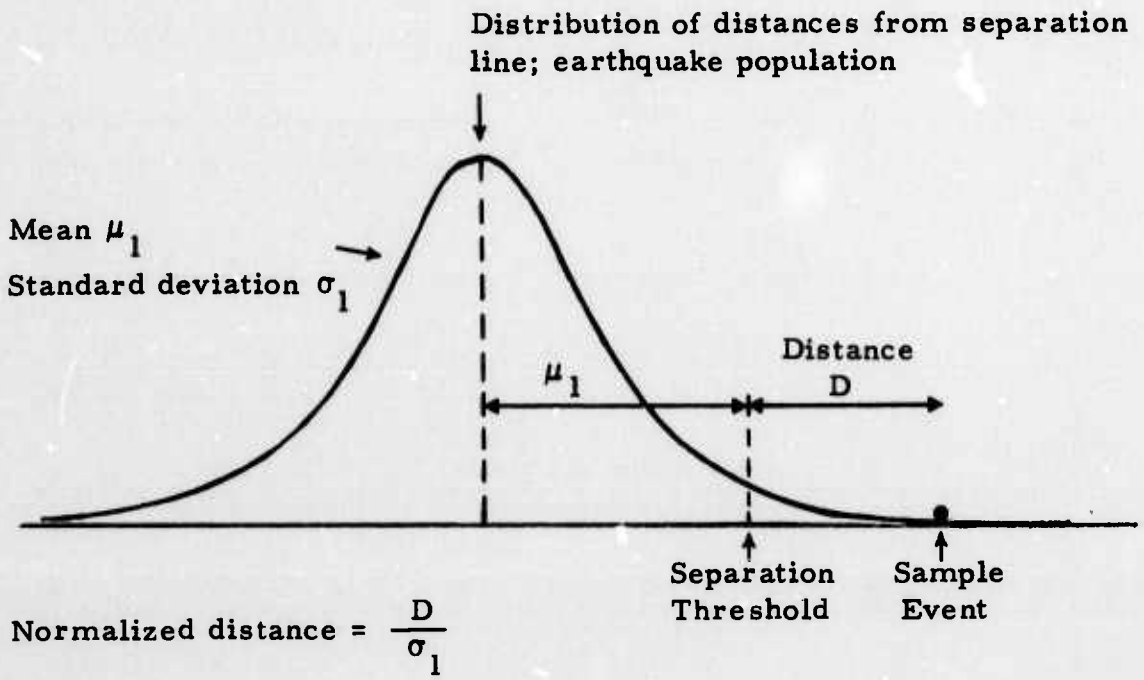

FIGURE II-12

ILLUSTRATION OF THE RELATIONSHIP BETWEEN THE EARTHQUAKE PROBABILITY DISTRIBUTION AND THE NORMALIZED DISTANCE FROM THE SEPARATION LINE

Among the presumed explosions, the following events were found to be difficult to classify properly:

- KAZ/356/06N; m_b = 6.0, M_s(Rayleigh) = 4.5, M_s(Love) = 3.3
  Distance = 25 degrees

  This presumed explosion from Western Kazakh had an unusually strong Rayleigh wave signal, and was a borderline decision for the two discriminants based on Rayleigh waves. Long and short period signal traces for this event are shown in Figures II-13 and II-14, respectively. The Love wave discriminants and the SP criteria worked well for this event.

- WKZ/233/02N; m_b = 5.7, M_s(Rayleigh) = 3.1, M_s(Love) = 2.8
  Distance = 24 degrees

  This presumed explosion had an epicenter very close to that of the event discussed above, KAZ/356/06N; the location difference being only about two degrees. Long and short period signal traces for WKZ/233/02N are displayed in Figures II-15 and II-16. There are marked differences between this event and KAZ/356/06N, in particular with respect to the relative amplitudes of the Love and Rayleigh waves. Also, when comparing the short period signal traces for the two events, it appears that WKZ/233/02N has less high frequency energy and also has a less impulsive signal onset than KAZ/356/06N. In fact, all the short period discriminants fail to classify WKZ/233/02N properly, while all four SP-LP criteria worked well for this event.

- EK1/345/04N; m_b = 5.7, M_s(Rayleigh) = 4.0, M_s(Love) = 4.2
  Distance = 38 degrees

  This presumed explosion was misclassified by four discriminants. The obvious reason for these problems is a second

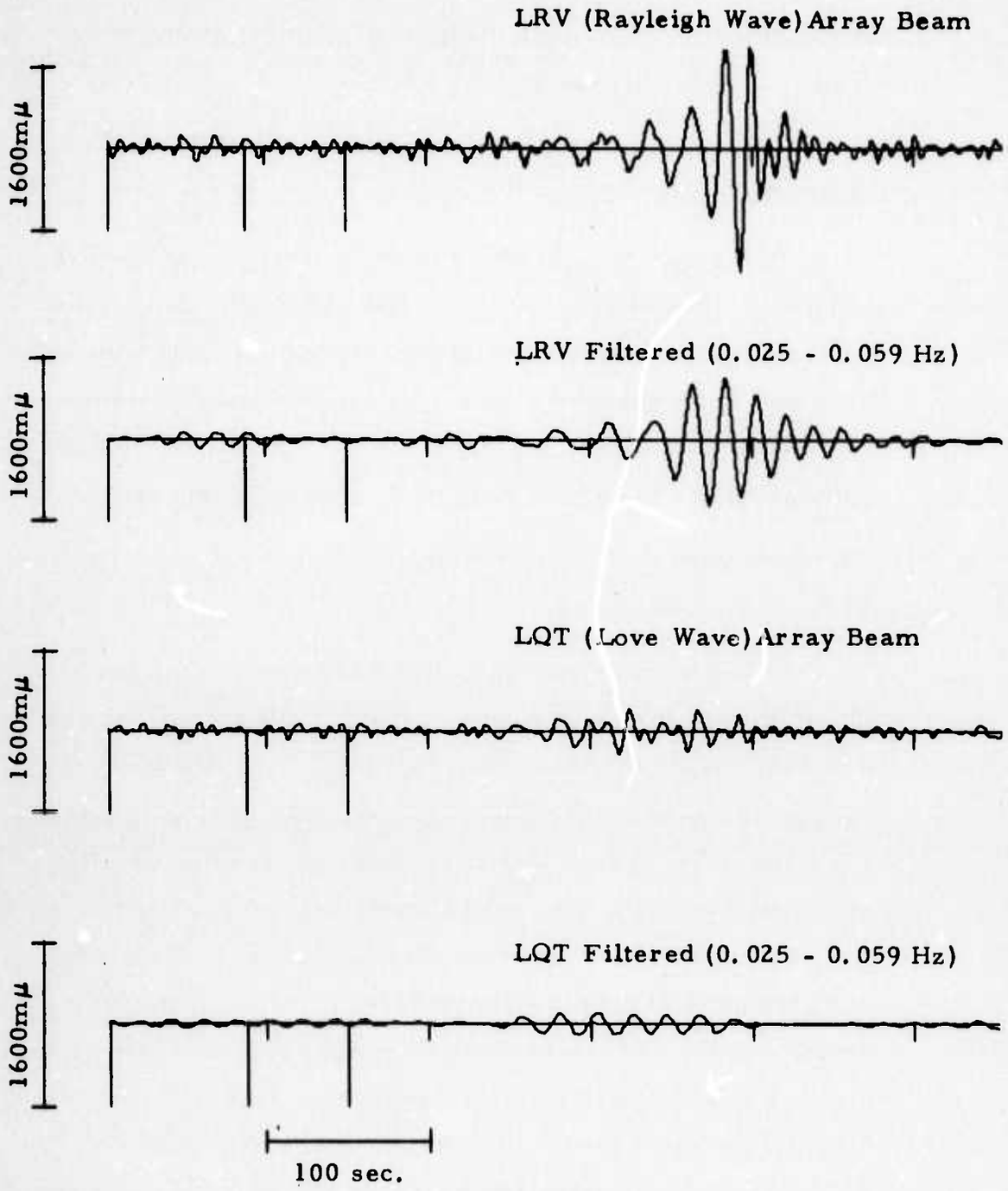

FIGURE II-13

LONG PERIOD TIME DOMAIN PLOT FOR EVENT
KAZ/356/06N

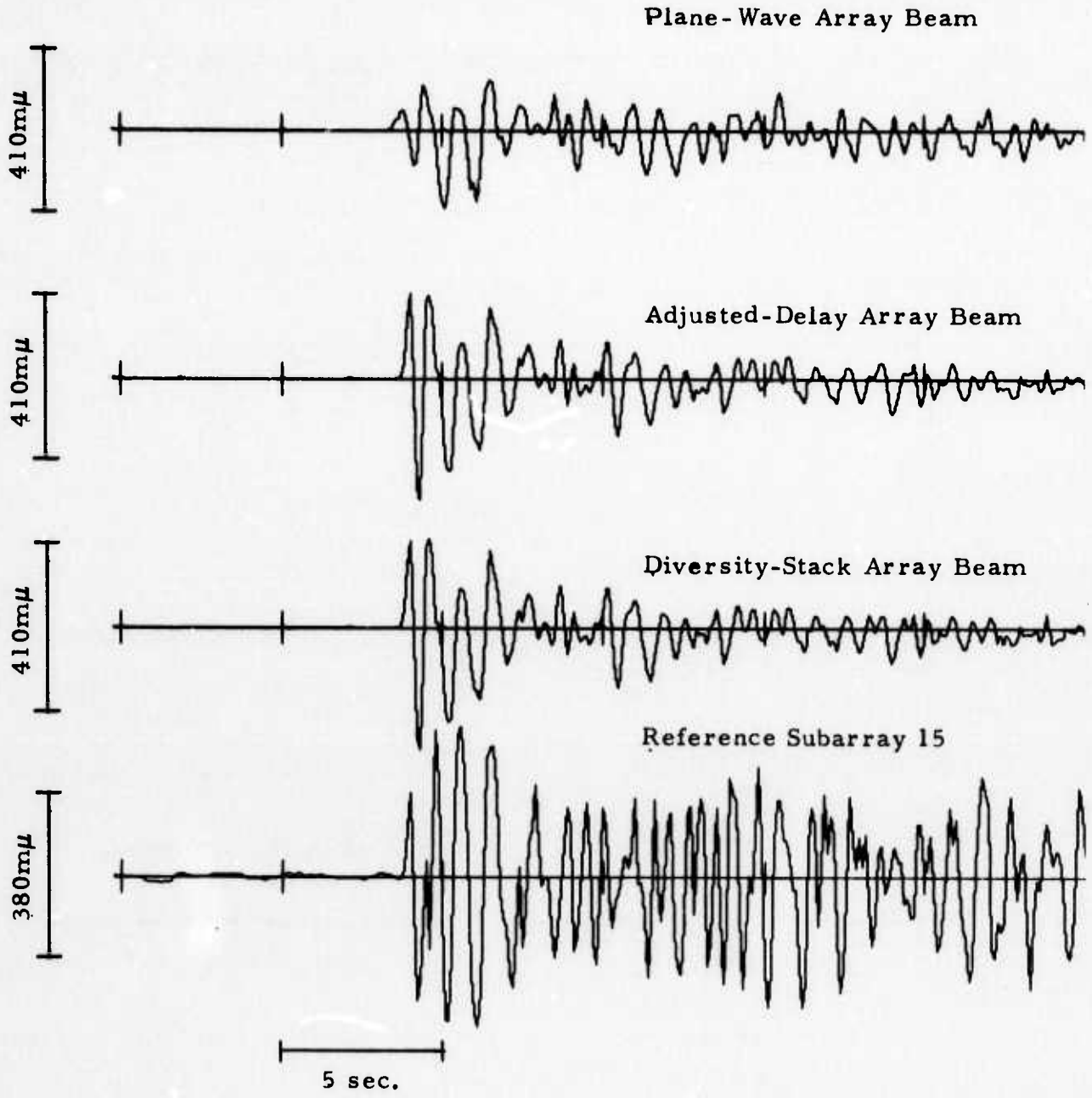

FIGURE II-14

SHORT PERIOD TIME DOMAIN PLOT FOR EVENT
KAZ/356/06N

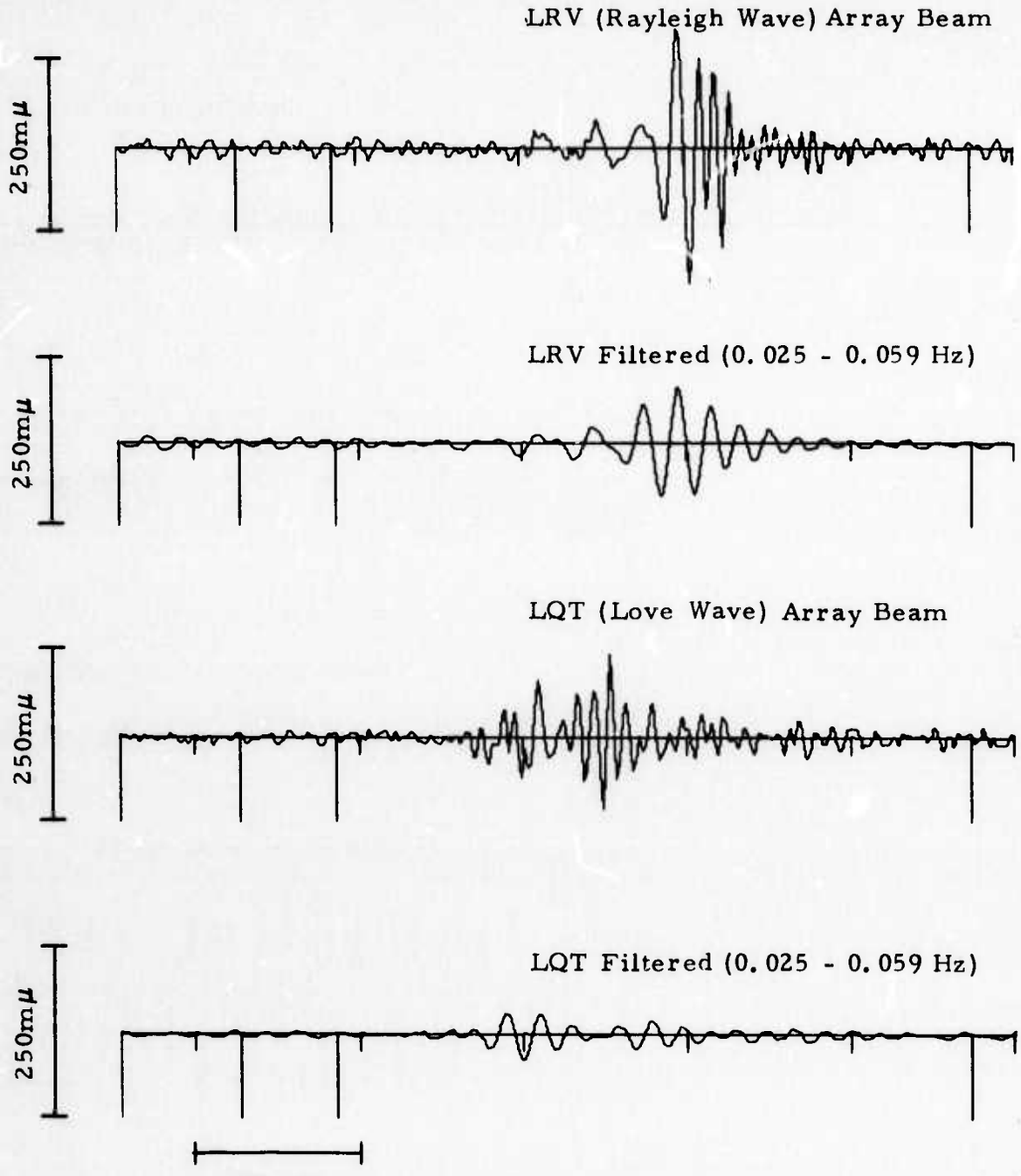

FIGURE II-15

LONG PERIOD TIME DOMAIN PLOT FOR EVENT
WKZ/233/02N

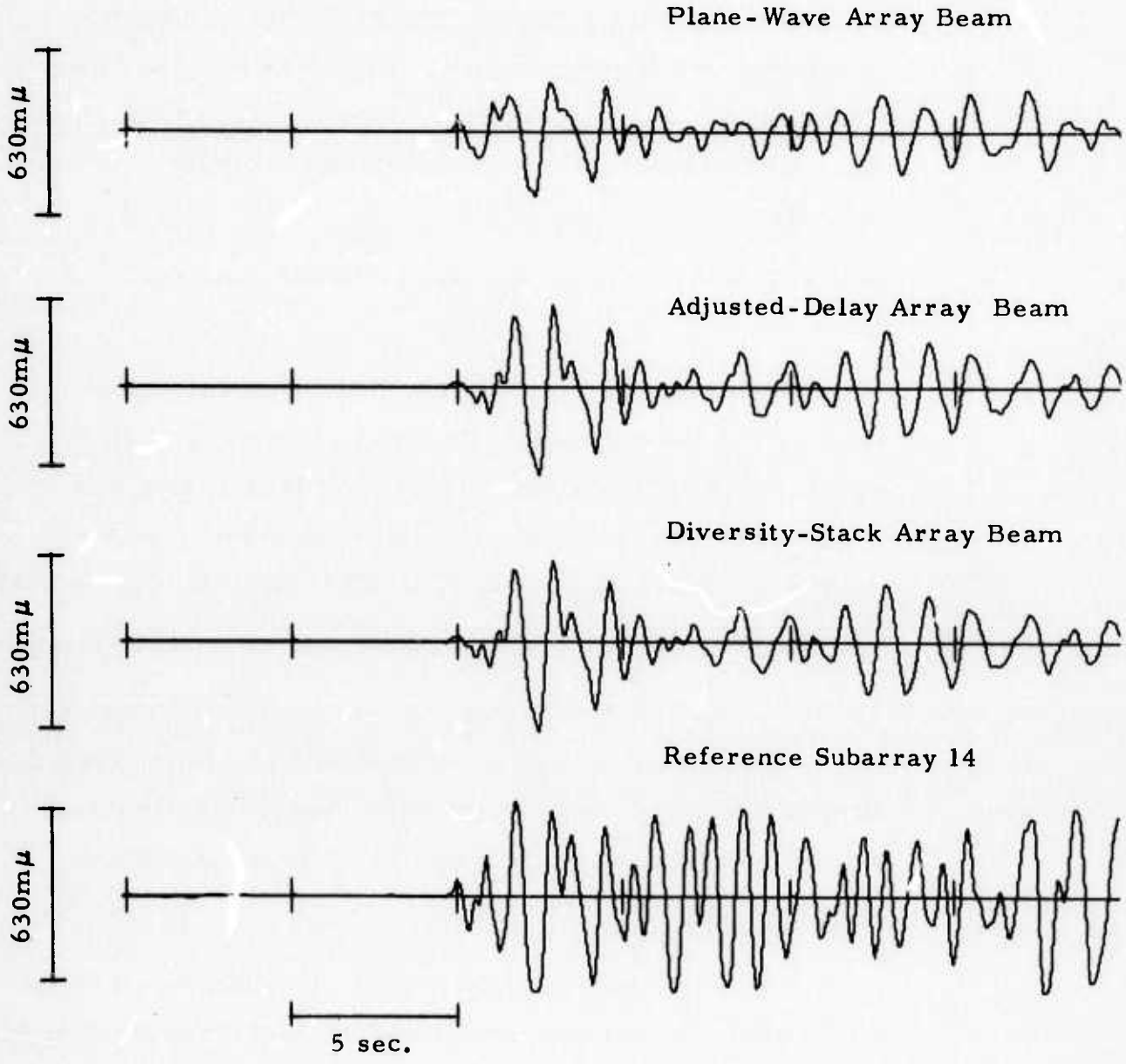

FIGURE II-16

SHORT PERIOD TIME DOMAIN PLOT FOR EVENT
WKZ/233/02N

presumed explosion from approximately the same location occurring just a few seconds later, with an amplitude about twice as large (Figure II-17). This of course distorts the complexity criteria (except for the autocorrelation) and also affects the M_s-m_b relationships. However, the SP discriminants based on spectral content were able to classify this event properly.

- EKZ/277/01N; m_b = 5.3, M_s(Rayleigh) = 3.5, Distance = 38 degrees

  This presumed explosion was misclassified by three short period discriminants. Figure II-18 is a plot of the SP signal traces for this event. There is noticeably less high frequency energy in this signal than has been observed for other Eastern Kazakh events, e.g., EK1/345/04N, Figure II-17.

- URA/191/16N, m_b = 5.3; EKZ/246/08N, m_b = 5.1; EKZ/349/07N m_b = 4.9

  No surface wave was detected at NORSAR for any of these three presumed explosions. However, the SP discriminants were able to place all three events in the proper category.

- EKZ/188/01N; m_b = 4.4

  This presumed explosion was misclassified by all SP discriminants. Surface waves were not detected for this event. It is thought that our SP criteria are not very effective for teleseismic events of a magnitude this low.

With respect to earthquakes, we proceed to briefly discuss those above m_b = 4.4 which failed to be classified properly by the four combined SP-LP discriminants.

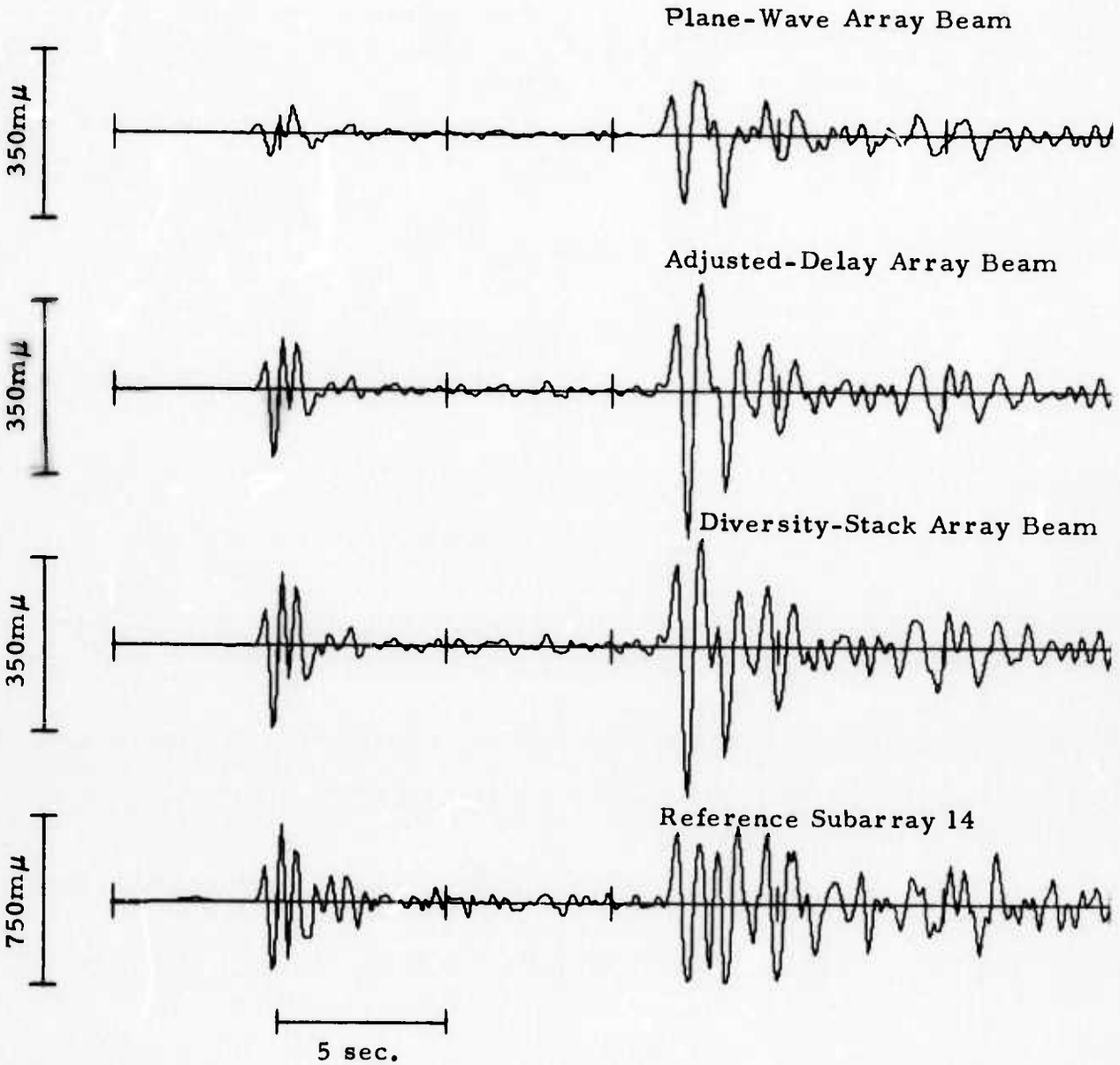

FIGURE II-17

SHORT PERIOD TIME DOMAIN PLOT FOR EVENT
EK1/345/04N

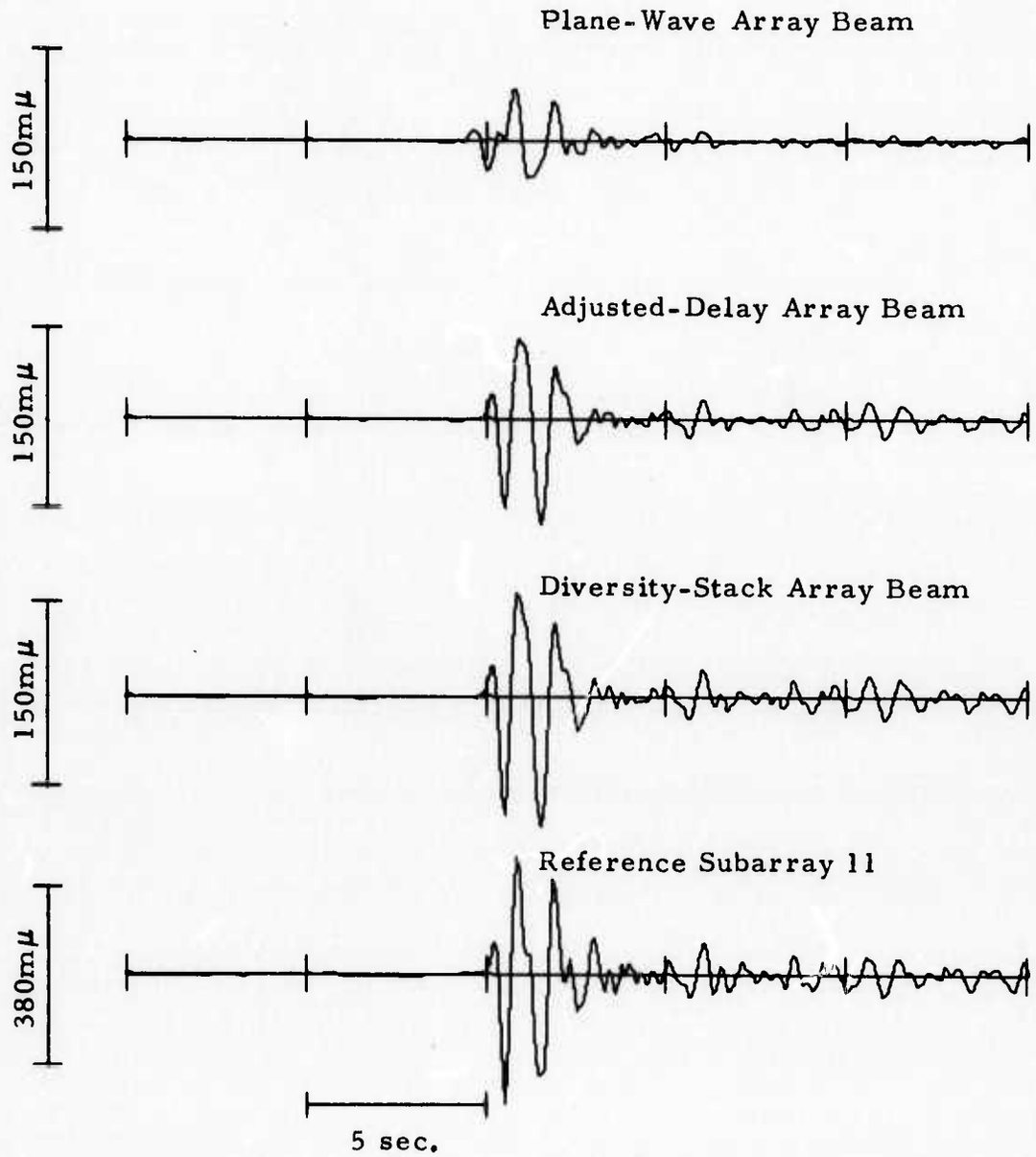

FIGURE II-18

SHORT PERIOD TIME DOMAIN PLOT FOR EVENT
EKZ/227/01N

- SIN/241/15N; m_b = 5.0

  Surface waves were not detected for this event. The event was misclassified by two of the six SP discriminants. The PDE m_b estimate of 5.0 for this event was based on just one station, and may be too high. The NORSAR m_b value for the event was 4.0.

- KAM/025/10N; m_b = 4.6 ; KAM/004/10N, m_b = 4.4

  These two events also had no surface wave detection at NORSAR. However, they were properly classified by the SP discriminants.

- YUG/180/01N, m_b = 4.6; M_s(Rayleigh) = 2.6, M_s(Love) = 3.1

  This event was misclassified by the M_s(Rayleigh)-m_b discriminant. We feel that this is because the m_b value reported by PDE may have been too high for this event. Our value of 4.6 is the average of the four teleseismic PDE stations that reported a magnitude. These four m_b values were 4.0, 4.0, 4.1, and 6.1, respectively. LASA reported m_b = 4.0 for this event, and the NORSAR m_b value computed by Texas Instruments was 3.5. A value of m_b around 4.0 would imply correct classification of this event by all discriminants.

It should in this context be noted that we have had several similar classification problems with events for which the PDE m_b value apparently has been too high, mainly because near regional stations have been used for the PDE determination (Special Report No. 12, 1973). In fact, unreliable m_b estimates appear to be a major obstacle in obtaining a satisfactory M_s - m_b separation for NORSAR data.

Table II-3 lists the computed probability of correct classification for each individual discriminant based on all events of $m_b \geq 4.4$. The

TABLE II-3

PROBABILITIES OF CORRECT IDENTIFICATION (SHALLOW EARTHQUAKE VERSUS PRESUMED EXPLOSION) BY INDIVIDUAL DISCRIMINANTS FOR EURASIAN EVENTS

Discriminants	All events $m_b \geq 4.4$			Common events $m_b \geq 4.4$		
	Number of Presumed Explosions	Number of Earthquakes	Probability of correct Identification	Number of Presumed Explosions	Number of Earthquakes	Probability of correct Identification
Log P30	23	75	0.93	12	46	0.92
Log Autocorrelation	23	75	0.88	12	46	0.92
Log Envelope Difference	23	75	0.92	12	46	0.93
Dominant Period	23	75	0.85	12	46	0.85
Spectral Ratio 3/1	23	75	0.92	12	46	0.92
Spectral Ratio 3/2	23	75	0.87	12	46	0.90
M_s(Rayleigh) - m_b	19	71	0.98	12	46	0.98
M_s(Love) - m_b	13	55	0.99	12	46	0.99
AR/m_b	18	60	0.99	12	46	0.985
AL/m_b	12	62	0.99	12	46	0.99

method described in the preceding subsection was used in this computation. For the purpose of comparing the individual discriminants, we also included in Table II-3 the probabilities of correct classification based upon only those events for which all nine discriminants had been evaluated. The following main points summarize the performance of the various discriminants:

- The four combined SP-LP criteria produce a much better separation between earthquakes and presumed explosions than the short period criteria.
- Probabilities of correct classification are 98-99 percent for the four SP-LP discriminants, while being around 90 percent for SP discriminants.
- The Love wave discriminants appear to give slightly better separation than the Rayleigh wave discriminants for the common event set, although the difference is only marginal.
- Of the SP discriminants, the ones based on complexity give the best separation. However, the presumed explosion population is heavily weighted toward Eastern Kazakh events (distance = 38 degrees), and results from Special Report No. 11 (1973) show that spectral discriminants in general are more effective when more close-in presumed explosions are included.

An important consideration when evaluating these discriminants is of course how often they can be applied. It appears that surface waves for Eurasian presumed explosions cannot in general be detected at NORSAR for events of m_b less than 5.0. Also, it seems to be possible to detect Rayleigh waves more often than Love waves, especially for presumed explosions. We have not tried to use the absence of visible surface waves as "negative evidence" of a presumed explosion, although this is certainly a way to extend the usefulness of the combined SP-LP discriminants.

In contrast to the above situation, short period discriminants may be applied at considerably lower magnitudes than those criteria that involve surface waves. However, our limited data indicate that SP discriminants do not perform very well for events of bodywave magnitude significantly below 5.0 (Special Report No. 11, 1973).

C. PERFORMANCE OF MULTIPLE DISCRIMINANTS

In order to evaluate what improvements may be expected from applying multiple discriminants, it is important to know their interdependence. Obviously, the more independent two discriminants are, the more improvement can be achieved by combining the two.

Table II-4 presents the results obtained by correlating discriminant values for the earthquakes of m_b at least 4.4 in the data base. The discriminant values from Table II-2 were used for this computation in order to minimize bias caused by m_b dependent discriminants. It was decided that the presumed explosion population (12 events) was too small to give any meaningful correlation estimates for this class of events. Although it should be stressed that Table II-4 only is intended to give a general idea of the relationship between discriminants, the following points may be made:

- Correlation is high (0.5 to 0.9) within each of the three subclasses
  - SP criteria based on complexity
  - SP criteria based on spectral contents
  - Combined SP-LP criteria
- Correlation is fairly high (0.3 to 0.7) across the two classes of SP criteria
- Correlation is low (0 - 0.5) between SP discriminants and combined SP-LP discriminants. However, there does appear to be a consistently positive correlation even in this case.

TABLE II-4

CORRELATION COEFFICIENTS BETWEEN DISCRIMINANT VALUES FOR EURASIAN EARTHQUAKES

		Correlated with									
		1	2	3	4	5	6	7	8	9	10
1	Log P30	1.									
2	Log Autocorrelation	0.51	1.								
3	Log Envelope Difference	0.87	0.67	1.							
4	Dominant Period	0.40	0.57	0.47	1.						
5	Spectral Ratio 3/1	0.46	0.60	0.53	0.83	1.					
6	Spectral Ratio 3/2	0.29	0.67	0.41	0.66	0.83	1.				
7	M_s(Rayleigh) - m_b	0.49	0.28	0.35	0.23	0.14	0.11	1.			
8	M_s(Love) - m_b	0.41	0.19	0.32	0.30	0.28	0.16	0.77	1.		
9	AR/m_b	0.26	0.13	0.20	0.06	0.05	0.03	0.61	0.57	1.	
10	AL/m_b	0.28	0.07	0.24	0.17	0.17	0.07	0.51	0.75	0.86	1.

It was indicated in Subsection II-A how the performance of two combined discriminants could be measured. Table II-5 presents the results achieved by combining the M_s(Rayleigh)- m_b discriminant with each of the other criteria. The table shows that the probability of correct identification typically improves from about 0.98 to about 0.99. Again, in view of the limited common event set (only 12 presumed explosions) these numbers must be interpreted merely as an indication of the expected improvements.

It would be desirable to present plots of combined discriminants in order to get a visual indication of the improvements achieved. However, this is not a straightforward task; for example, a plot of Spectral Ratio versus M_s would produce severe overlap between the presumed explosion and earthquake populations. This is because both discriminants are inherently dependent upon m_b, and will not produce good separation if m_b is ignored. A better result is achieved using the AL and AR discriminants, which have already been normalized with respect to m_b. Figures II-19 through II-22 present combinations of these two discriminants and two SP criteria (Log P30 and Spectral Ratio).

These plots are somewhat inconclusive with respect to the potential of combined discriminants, since they do not demonstrate any definite improvement in separation compared to the individual plots for AR/m_b and AL/m_b (Figures II-4 and II-5). It appears that the main contribution from SP discriminants would be to give evidence to corroberate indications of earthquake or presumed explosion already provided by the SP-LP criteria. In addition, of course, the SP discriminants are valuable in those cases when surface waves cannot be detected.

TABLE II-5

PROBABILITIES OF CORRECT IDENTIFICATION (SHALLOW EARTHQUAKE VERSUS PRESUMED EXPLOSION) FOR DISCRIMINANTS COMBINED WITH M_s(RAYLEIGH) - m_b

	Discriminant	Individual Discriminant	Combined with M_s(Rayleigh)- m_b
1	Log P30	0.92	0.985
2	Log Autocorrelation	0.92	0.99
3	Log Envelope Difference	0.93	0.985
4	Dominant Period	0.85	0.99
5	Spectral Ratio 3/1	0.92	0.99
6	Spectral Ratio 3/2	0.90	0.99
7	M_s(Rayleigh) - m_b	0.98	0.98
8	M_s(Love) - m_b	0.99	0.99
9	AR/m_b	0.985	0.985
10	AL/m_b	0.99	0.99

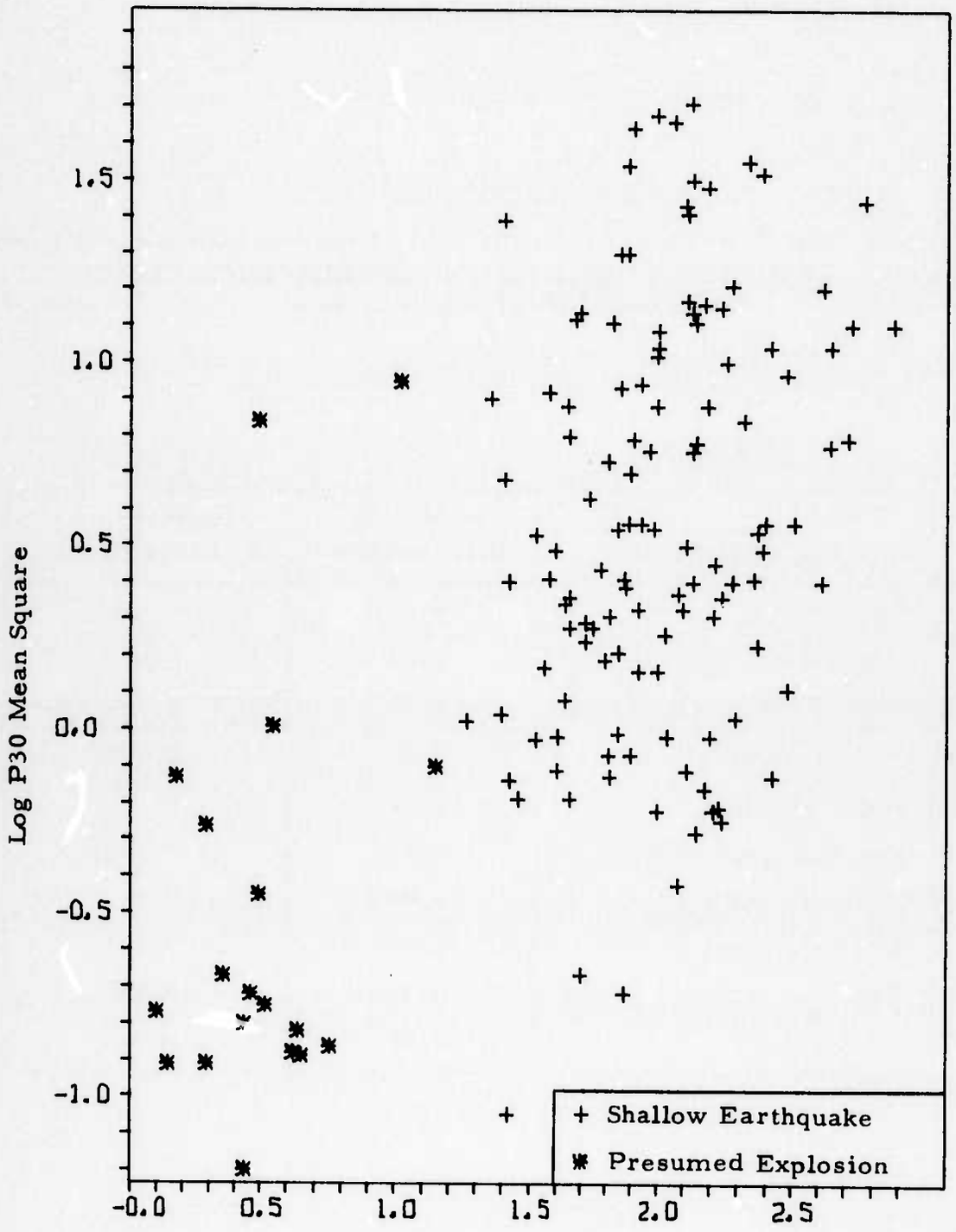

FIGURE II-19

AR VERSUS P30 DISCRIMINANT

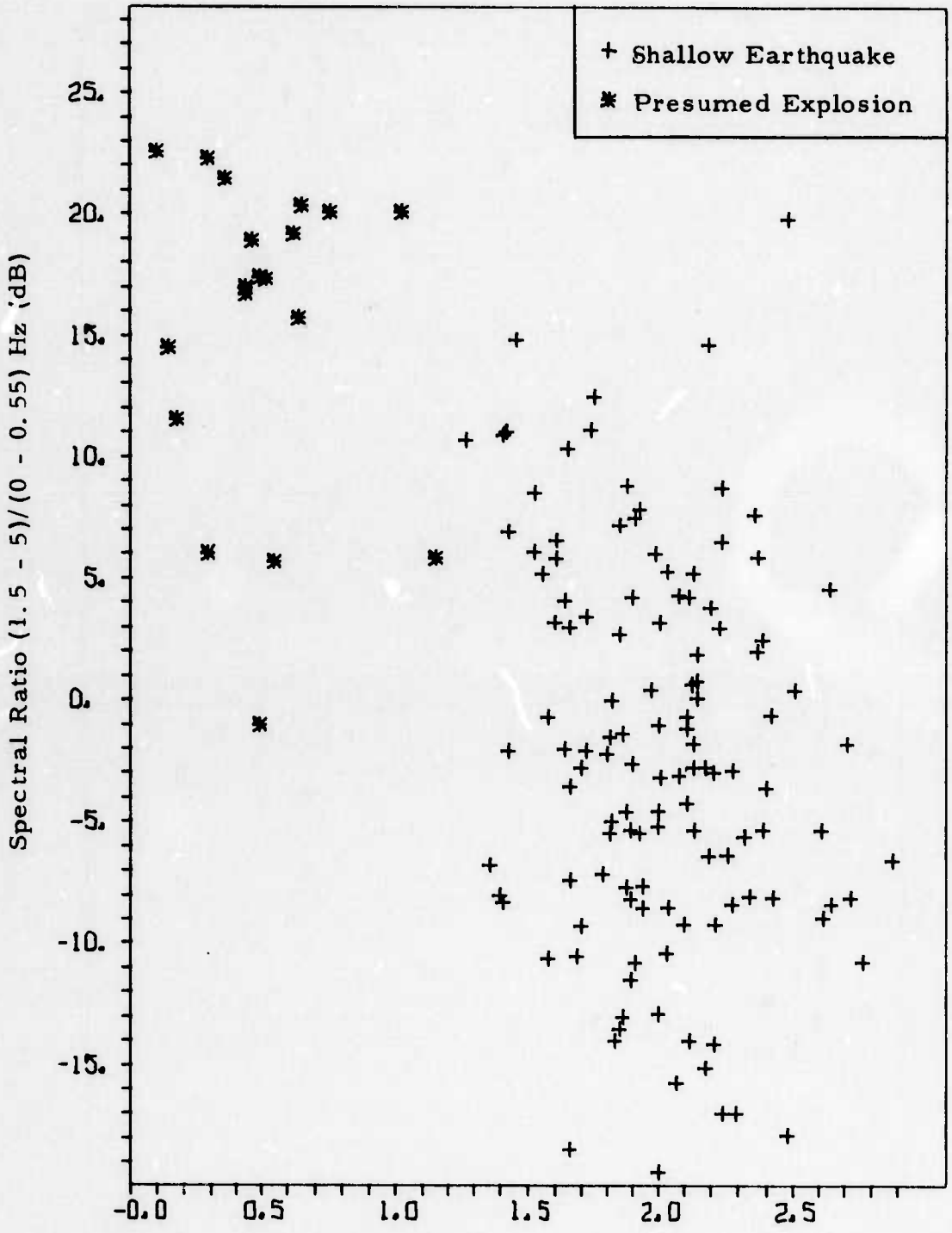

FIGURE II-20

AR VERSUS SPECTRAL RATIO (1.5 - 5)/(0 - 0.55) Hz DISCRIMINANT

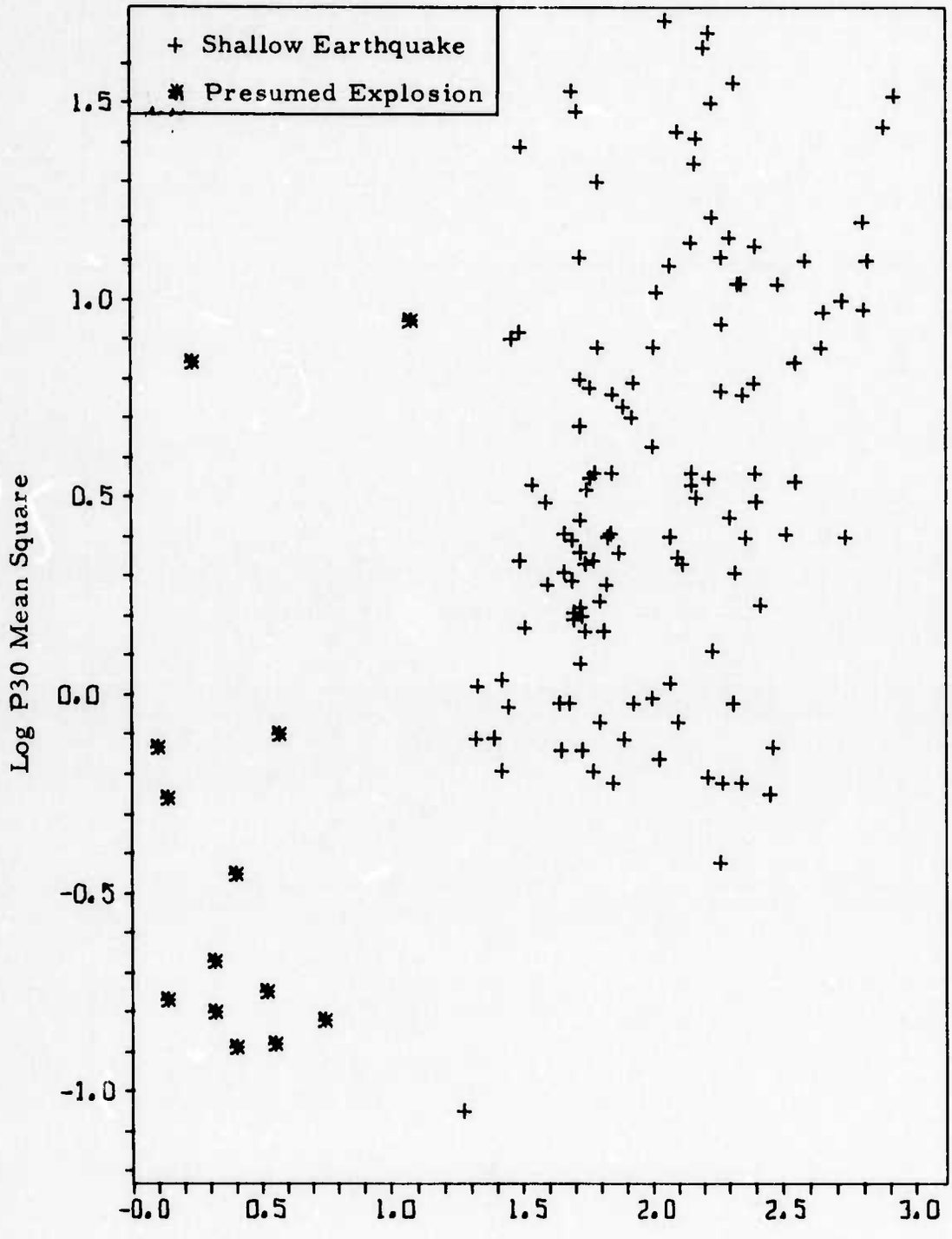

FIGURE II-21

AL VERSUS P30 DISCRIMINANT

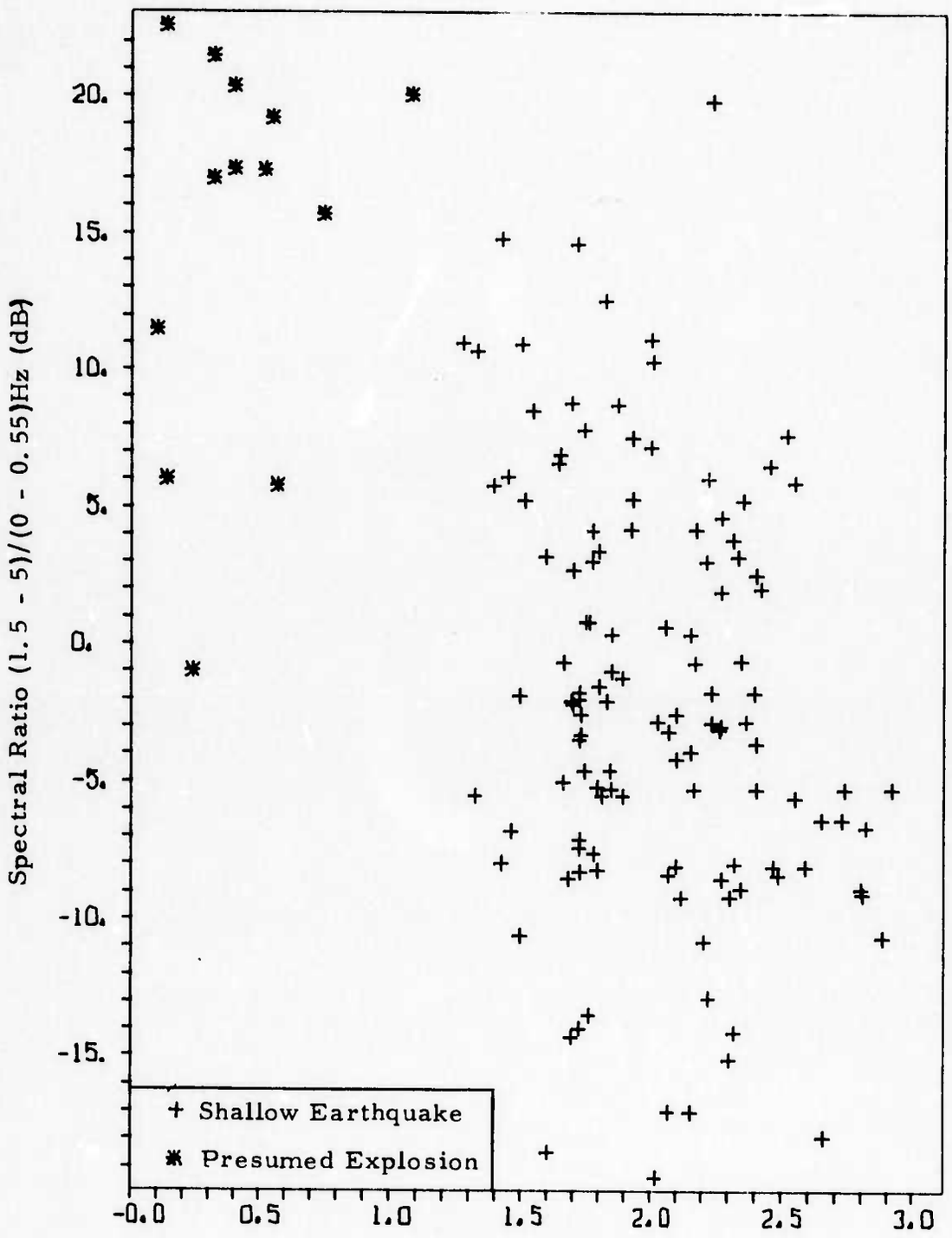

FIGURE II-22

AL VERSUS SPECTRAL RATIO (1.5 - 5)/(0 - 0.55) Hz
DISCRIMINANT

SECTION III
SUMMARY AND CONCLUSIONS

The capability of the short and long period Norwegian Seismic Array (NORSAR) to discriminate between Eurasian earthquakes and presumed explosions has been evaluated. The total data base consists of 257 events, 24 of which are presumed explosions. All of the earthquakes are either shallow or of unknown depth. The majority of the presumed explosions (19) occurred in Eastern Kazakh, at a distance from NORSAR of 38 degrees. Bodywave magnitudes for the events in the data base ranged from 5.6 to 2.7 for the earthquakes and from 6.3 to 4.4 for the presumed explosions.

A total of nine standard discriminants have been analyzed. Four of these are combined SP-LP criteria, which compare Love or Rayleigh wave energy recorded at NORSAR to bodywave magnitude. Three are SP discriminants based on waveform complexity while the remaining two measure the SP spectral energy distribution.

The major results from this study can be summarized as follows:

- All of the 24 presumed explosions and approximately 90 percent of the earthquakes in the data base were detected on NORSAR Short Period data.
- Twenty of the 24 presumed explosions and approximately 70 percent of the earthquakes in the data base were detected on NORSAR Long Period data.
- Rayleigh waves were detected more often than Love waves for the presumed explosions (20 detections as compared to 14). For

the earthquake population, the detectability of Rayleigh waves was only slightly better than that of Love waves.

- Each of the four discriminants based on surface wave measurements gave markedly better separation between earthquakes and presumed explosions than any of the short period criteria.

- All of the four combined SP-LP discriminants produced close to complete separation for our event set. The M_s(Love)- m_b discriminant appeared to give a more distinct separation than M_s(Rayleigh)-m_b, although the latter one could be applied to more events. The AR/m_b and AL/m_b discriminants performed about equally well on the common event set.

- Of the short period discriminants, complexity criteria worked slightly better than the spectral ones. However, it appears that the spectral discriminants perform relatively better for close-in presumed explosions.

- The combined SP-LP discriminants were not able to give positive identification for events of m_b = 5.0 and lower, since surface waves could not in general be detected at NORSAR for presumed explosions in this magnitude range. However, if "negative evidence" (i.e., the absence of detectable surface waves) is accepted as a way to identify a presumed explosion, the NORSAR SP-LP discriminants appear to be effective down to approximately m_b = 4.5. This is because surface waves are detected for virtually all Eurasian earthquakes above this magnitude.

- The short period discriminants worked relatively well for events of m_b close to 5.0. However, based on our limited presumed explosion data, indications are that our SP discriminants

cannot be expected to operate well at m_b significantly below 5.0 at teleseismic distances.

- Correlation is high between discriminants within each of the three subclasses (combined SP-LP, SP complexity, SP spectral content). However, the combined SP-LP criteria are only slightly correlated with the SP discriminants, thus indicating that some improvement may result from multivariate criteria.

- Detailed analysis of some "difficult" events indicates that there are cases where SP discriminants work better than one of the four combined SP-LP criteria. However, in view of the high false alarm rate (close to 10 percent) for our SP discriminants, it appears that decisions (earthquake versus presumed explosion) based on SP information alone will generally have a substantial probability of error. The main benefit of the standard SP discriminants thus appears to be to provide corroborative evidence to the SP-LP criteria.

- Since all the discriminants studied in this report are m_b dependent, it is essential to have a precise estimate of this parameter. It appeared that in some cases where we misclassified an earthquake the main problem was an unreliable m_b estimate.

It is important to remember that these conclusions are based on the performance of a single array at teleseismic distances; they are not necessarily applicable to network discrimination performance or to first-zone ($\Delta < 15^{\circ}$) discrimination capability.

SECTION IV
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APPENDIX A
DISCRIMINATION STATISTICS

Tables A-1 and A-2 list the discriminant values computed for each event in the data base for this report. These values are identical to those used for the plots of individual discriminants in Figures II-2 through II-11. Events are ordered from high to low bodywave magnitude. Discriminant values are listed in the following order:

1. M_s (Rayleigh wave)
2. M_s (Love wave)
3. Log AR (Rayleigh wave energy)
4. Log AL (Love wave energy)
5. Log P30 Mean Square
6. Log Autocorrelation Mean Square
7. Log Envelope Difference
8. Dominant Period (Seconds)
9. Spectral Ratio (1.5 - 5)/(0 - 0.55)Hz (Band 3/Band1) in dB
10. Spectral Ratio (1.5 - 5)/(0.55 - 1.5)Hz (Band 3/Band 2) in dB

For those events that had no detection of Rayleigh waves, Love waves or short period P-waves, the corresponding discriminant values have not been computed. Also, in some cases the occurrence of data spikes made it impossible to apply one or more long period discriminants. Finally, it should be noted that M_s (Love) was not computed for any of the 18 earthquakes from 1971.

TABLE A-1

DISCRIMINATION STATISTICS (PRESUMED EXPLOSIONS)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG AR	LOG AL	LOG P30	LOG AUTO	LOG ENVD	DOM PER	SP.RAT P3/P1	SP.RAT P3/P2
EKZ/204/01N	C	6.3	4.1	3.7	0.49	-	0.01	-0.09	2.31	0.74	5.7	-10.9
EKZ/307/01N	0	6.2	3.8	3.7	0.23	0.08	-0.26	-0.36	2.08	0.71	6.0	-4.7
KAZ/356/06N	0	6.0	4.5	3.3	1.09	0.51	-0.10	-0.35	2.12	0.60	5.8	-4.7
EKZ/364/06N	C	5.8	2.9	3.6	0.59	0.34	-0.89	-1.01	2.05	0.63	20.4	2.2
SWR/277/08N	0	5.8	2.9	2.7	0.11	0.04	-0.13	-0.42	2.07	0.89	11.5	-7.0
WKZ/233/02N	0	5.7	3.1	2.8	0.43	0.18	0.84	-0.18	2.51	1.18	-1.0	-10.7
EK1/345/04N	0	5.7	4.0	4.2	0.96	1.02	0.95	-1.02	2.56	0.53	20.1	2.9
EKZ/294/06N	0	5.6	3.1	3.1	0.43	0.34	-0.45	-1.01	1.88	0.59	17.4	0.1
EKZ/047/05N	0	5.6	3.0	3.0	0.58	0.69	-0.82	-1.08	2.08	0.53	15.7	0.1
KAZ/157/04N	0	5.5	3.5	2.7	0.30	0.26	-0.67	-0.78	1.99	0.54	21.5	3.7
KAZ/170/04N	0	5.5	3.3	2.9	0.04	0.08	-0.77	-0.91	1.92	0.52	22.6	4.1
EKZ/333/06N	0	5.5	3.4	3.2	0.46	0.46	-0.75	-0.79	1.88	0.60	17.3	-4.1
EKZ/041/05N	0	5.5	2.7	-	0.08	-	-0.91	-0.74	1.82	0.76	14.5	-4.7
KAZ/070/04N	C	5.5	3.3	3.3	0.38	0.26	-0.80	-0.80	1.70	0.60	17.0	-3.3
KAZ/282/06N	C	5.4	2.8	-	0.40	-	-0.72	-0.84	1.87	0.51	18.9	2.5
URA/191/16N	C	5.3	-	-	-	-	-0.27	-0.61	2.01	0.46	28.0	4.7
EKZ/227/01N	0	5.3	3.5	-	-	-	-0.46	-0.39	1.93	0.97	11.8	-10.1
EKZ/240/03N	0	5.3	2.8	-	0.38	-	-1.20	-0.94	2.02	0.54	16.7	-3.8
KAZ/145/04N	0	5.2	2.6	-	0.23	-	-0.91	-0.85	2.01	0.51	22.3	5.7
EKZ/088/04N	0	5.2	2.9	2.8	0.56	0.49	-0.88	-0.82	1.85	0.56	19.2	-3.4
EKZ/229/03N	0	5.2	3.1	-	0.70	-	-0.86	-0.97	2.03	0.55	20.1	1.7
EKZ/246/08N	0	5.1	-	-	-	-	-0.33	-0.84	2.08	0.54	13.8	2.3
EKZ/349/07N	0	4.9	-	-	-	-	-0.29	-0.73	1.95	0.49	9.1	10.2
EKZ/188/01N	0	4.4	-	-	-	-	-0.47	-0.78	1.98	0.56	7.2	-2.3

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 1 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG AR	LOG AL	LOG P30	LOG AUTO	LOG ENVD	PDM PER	SP.RAT P3/P1	SP.RAT P3/P2
KUR/213/02N	20	5.6	5.4	-	-	-	0.07	-0.54	2.16	0.79	15.3	-4.6
UAR/180/09N	15	5.6	4.6	4.8	2.15	2.27	0.31	-0.32	2.40	1.45	-14.1	-16.0
PAK/179/06N	12	5.5	4.9	4.6	1.87	1.75	0.16	-0.39	2.12	1.26	-5.5	-14.0
TIB/204/16N	33	5.5	5.3	6.1	2.33	2.86	1.52	-0.45	2.90	1.14	-5.3	-6.4
TIB/123/00N	16	5.4	5.2	-	2.17	2.16	-0.21	-0.45	2.14	0.75	3.0	-4.8
IR1/164/13N	33	5.4	4.7	5.3	2.30	2.46	0.41	-0.61	2.28	0.88	7.6	-3.5
IRA/184/12N	31	5.4	4.8	5.3	-	2.75	0.98	-0.38	2.71	0.94	-9.1	-5.3
SIB/013/17N	33	5.3	5.2	5.0	2.65	2.34	0.79	-0.06	2.35	0.59	-1.8	-0.5
TIB/075/06N	33	5.3	3.9	3.9	1.21	1.27	0.02	-0.17	2.32	0.64	10.7	-3.6
IRA/166/04N	33	5.3	3.9	4.4	1.66	1.74	0.24	-0.24	2.27	0.86	3.4	-8.8
KAM/199/08N	33	5.3	4.2	4.2	1.60	1.54	0.28	0.05	2.29	1.24	-19.5	-23.2
KIR/170/17N	33	5.2	5.3	-	2.31	2.49	0.54	-0.29	2.45	0.81	5.9	-3.6
SIN/002/10N	33	5.2	4.2	4.2	1.47	1.48	0.53	-0.44	2.26	0.83	8.5	-6.6
KUR/077/07N	33	5.2	4.5	4.1	1.79	1.64	0.21	-0.17	2.20	0.83	2.7	-7.7
TAD/077/03N	33	5.2	4.9	4.5	2.22	2.18	1.21	-0.57	2.54	0.84	-2.9	-3.0
KUR/193/06N	33	5.2	4.0	-	1.64	-	1.14	0.31	2.63	0.93	-9.3	-5.3
TIB/199/02N	33	5.2	4.3	4.6	-	1.67	-0.14	-0.25	2.20	1.17	-3.3	-16.5
KAM/166/14N	55	5.1	4.7	-	1.84	1.86	0.70	-0.13	2.32	1.08	4.2	-10.3
IRA/014/22N	33	5.1	3.7	4.0	1.60	1.71	-0.19	-0.41	2.23	0.74	3.0	-4.1
IRA/165/00N	27	5.1	4.1	4.6	2.14	2.26	-0.02	-0.41	2.28	0.62	3.8	-1.1
HIN/179/15N	53	5.1	4.4	3.8	2.13	1.65	1.49	-0.43	2.36	0.56	14.6	-2.5
KUR/209/00N	33	5.1	4.6	4.6	2.07	2.00	1.71	-0.20	2.89	0.70	0.6	-7.6
RYU/209/16N	33	5.1	4.5	4.9	1.85	2.15	1.64	-0.23	2.89	1.04	-10.8	-17.0
SIN/241/15N	33	5.0	-	-	-	-	0.56	-1.06	2.38	0.67	6.9	2.4
KUR/055/10N	33	5.0	4.9	4.5	2.45	2.10	0.56	-0.48	2.38	0.75	0.4	-8.2

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 2 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG AR	LOG AL	LOG P30	LOG AUTO	LOG ENVD	DCM PEP	SP.RAT P3/P1	SP.RAT P3/P2
RYU/155/02N	33	5.0	4.7	4.7	1.88	1.72	0.56	-0.20	2.44	1.05	-7.6	-17.0
TAI/178/08N	33	5.0	4.8	5.1	2.12	2.25	1.16	0.13	2.78	1.62	-15.1	-23.5
IRA/195/02N	33	5.0	4.0	3.8	1.80	-	0.93	-0.45	2.56	0.83	-1.4	-8.1
TUR/161/09N	33	4.9	4.3	-	-	-	0.98	-0.21	2.64	1.21	-0.7	-12.5
KIR/166/23N	33	4.9	4.1	-	1.35	1.44	1.39	-0.28	3.02	0.64	10.9	-2.6
KUR/190/16N	46	4.9	4.9	-	2.33	2.35	0.49	-0.22	2.45	0.75	2.5	-5.5
CRE/012/13N	33	4.9	4.2	3.9	2.42	2.18	0.11	-0.33	2.24	0.64	19.8	-2.7
IRA/018/21N	33	4.9	3.4	3.9	1.68	1.94	0.63	-0.32	2.46	0.58	11.1	3.0
SIN/042/05N	33	4.9	4.2	4.3	1.75	1.83	0.72	-0.33	2.46	1.06	-5.5	-10.0
KUR/057/05N	33	4.9	3.5	3.5	1.36	1.21	-1.05	-1.05	1.92	0.66	11.0	-4.1
LOM/058/10N	33	4.9	3.9	3.6	2.18	2.10	1.15	-0.12	2.59	1.54	-17.0	-17.0
TAI/160/10N	33	4.9	4.5	4.6	1.81	1.78	0.41	-0.20	2.36	1.19	-4.6	-11.6
CRE/161/07N	33	4.9	4.0	4.1	2.36	2.29	1.04	-0.40	2.58	0.96	-0.6	-7.5
GRE/167/00N	26	4.9	4.2	4.3	2.66	2.53	1.10	-0.05	2.74	1.21	-8.1	-9.0
TAI/182/18N	33	4.9	4.8	5.4	2.13	2.59	0.88	-0.43	2.56	1.55	-6.4	-8.7
TUR/198/02N	33	4.9	4.4	4.7	2.71	2.82	1.44	0.01	2.79	1.21	-10.7	-16.6
TAC/147/00N	36	4.8	4.1	-	1.83	1.79	0.56	-0.22	2.32	0.95	-5.3	-12.7
KUR/191/03N	36	4.8	4.4	-	1.98	1.87	-0.02	-0.68	1.94	0.75	5.3	-4.7
TUR/251/22N	33	4.8	4.4	-	2.42	2.60	0.97	0.03	2.66	1.96	-17.9	-16.6
KAM/003/06N	33	4.8	3.9	3.9	1.75	1.74	-0.07	-0.09	2.28	0.79	-1.5	-15.2
KAM/012/20N	33	4.8	4.2	4.3	2.06	2.12	1.41	-0.40	2.75	0.80	4.2	-4.7
DOD/020/02N	33	4.8	4.0	3.7	2.23	2.01	0.03	-0.01	2.20	1.16	-17.0	-20.0
KAM/052/22N	33	4.8	3.7	-	1.76	-	-0.13	-0.60	1.95	0.94	0.0	-12.2
KUR/054/03N	41	4.8	4.0	4.3	1.79	1.94	-0.01	-0.64	2.15	0.66	7.2	-4.3
PAK/157/11N	27	4.8	3.5	3.6	1.30	1.40	0.90	-0.60	2.35	0.98	-6.8	-7.5

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 3 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG AR	LOG AL	LOG P30	LOG AUTO	LOG ENVD	DOM PER	SP.RAT R3/P1	SP.RAT R3/R2
SZE/203/16N	33	4.8	4.2	4.1	1.91	1.79	0.76	0.51	2.85	1.19	0.4	-12.4
KUR/211/21N	33	4.8	4.1	3.9	1.72	1.66	0.44	-0.18	2.31	0.94	-7.1	-17.9
KAM/213/06N	33	4.8	3.6	3.6	1.55	1.33	-0.11	-0.58	2.14	0.64	5.9	-3.2
NEC/156/10N	33	4.7	5.0	-	2.26	2.49	0.84	-0.32	2.52	0.80	-5.6	-10.4
TAI/006/06N	33	4.7	4.0	4.2	1.54	1.53	0.49	-0.05	2.36	0.84	3.2	-11.0
KUR/049/18N	33	4.7	3.8	3.8	1.58	1.71	0.34	-0.39	2.34	0.78	4.1	-8.0
YUN/057/18N	33	4.7	3.9	4.0	1.55	1.58	-0.02	-0.43	2.18	0.70	6.6	-2.2
KAM/078/18N	33	4.7	3.5	3.5	1.52	1.43	0.92	-0.26	2.43	1.30	-10.6	-11.6
CAS/166/00N	47	4.7	3.7	3.2	1.87	1.68	0.33	-0.58	2.19	0.71	7.9	-7.3
HIN/177/07N	46	4.7	4.4	4.2	2.58	2.22	0.77	-0.25	2.53	0.76	4.6	-6.1
TIB/198/03N	33	4.7	3.8	4.1	-	1.69	0.52	-0.22	2.40	0.95	0.8	-4.4
TIB/204/21N	33	4.7	3.1	3.8	-	1.43	0.34	-0.41	2.44	1.21	-1.9	-8.2
TUR/126/04N	23	4.6	4.4	-	-	-	1.11	-0.22	2.86	1.22	-16.2	-17.5
CAS/135/04N	33	4.6	3.3	-	1.52	1.60	0.41	-0.52	2.24	0.94	-0.7	-9.5
KUR/191/09N	33	4.6	3.4	-	-	-	0.18	-0.67	2.17	0.50	7.0	3.6
KUR/001/16N	33	4.6	-	3.6	-	1.43	1.53	0.21	2.86	0.38	-14.3	-1.0
TAI/004/12N	33	4.6	4.9	5.1	2.54	2.74	1.20	-0.09	2.61	1.14	-8.9	-7.4
KAM/025/10N	33	4.6	-	-	-	-	0.19	-0.50	2.16	0.77	-3.4	-6.7
KAM/042/21N	33	4.6	3.9	4.2	2.08	2.18	1.50	-0.46	2.75	0.38	-1.8	-7.4
IRA/068/21N	45	4.6	3.7	3.5	1.82	1.63	0.39	-0.13	2.36	0.70	8.8	-5.4
YUG/180/01N	33	4.6	2.6	3.1	1.35	1.66	0.68	-0.33	2.61	0.85	-8.3	-8.7
AFG/181/03N	53	4.6	3.9	3.8	1.85	1.87	0.79	-0.48	2.57	0.62	7.5	0.4
IRA/184/14N	31	4.6	3.3	3.3	1.66	1.63	0.29	-0.40	2.31	0.98	-2.1	-5.4
TAI/198/13N	33	4.6	4.5	4.2	2.09	1.70	0.78	-0.29	2.44	0.82	0.9	-6.3
BLS/210/19N	33	4.5	2.6	-	-	-	0.07	-0.31	2.38	0.86	1.5	-9.9

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 4 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG AR	LOG AL	LOG P30	LOG AUTO	LOG ENVD	DOM PER	SP.RAT P3/P1	SP.RAT P3/P2
KAM/003/19N	33	4.5	-	3.5	-	1.66	0.22	-0.11	2.36	0.77	-1.9	-12.2
KUR/005/02N	33	4.5	3.4	3.2	1.50	1.45	0.17	-1.40	2.11	0.48	5.2	4.7
TAD/005/12N	33	4.5	3.0	2.9	1.34	1.36	0.04	-0.21	2.63	0.99	-8.0	-7.0
YUN/034/07N	33	4.5	4.1	4.5	2.08	2.31	0.40	-0.27	2.32	0.94	-2.9	-8.2
GRE/044/13N	33	4.5	3.2	3.8	1.95	2.23	1.04	-0.34	2.89	0.82	3.2	-10.0
GRE/047/00N	33	4.5	2.9	3.4	1.59	1.95	0.88	-0.19	2.89	0.75	10.2	-6.4
PAI/058/22N	33	4.5	3.1	3.0	1.40	1.36	-0.19	-0.30	2.32	0.59	14.8	-0.2
KUR/063/23N	33	4.5	3.8	3.5	1.94	1.68	0.16	-0.28	2.52	1.18	-4.6	-3.0
SIN/064/04N	33	4.5	3.9	3.6	1.94	1.73	0.88	-0.69	2.38	1.21	-5.2	-6.1
CHI/066/23N	33	4.5	-	-	-	-	-	-	-	-	-	-
PAK/162/11N	33	4.5	3.8	3.8	2.02	-	0.37	-0.38	2.38	0.57	4.3	-3.0
KUZ/171/18N	33	4.5	3.7	3.5	1.76	1.60	0.31	0.01	2.36	1.05	-5.0	-13.0
KAM/199/20N	33	4.5	-	3.0	-	1.26	-0.11	-0.31	2.26	1.37	-5.5	-13.1
TUR/143/01N	33	4.4	4.0	-	-	-	0.50	-0.42	2.46	1.16	1.6	-6.5
KAM/004/10N	33	4.4	-	-	-	-	-0.33	-0.22	2.36	0.69	-3.4	-2.6
TUR/022/17N	33	4.4	2.7	2.6	-	-	1.10	-0.64	2.54	1.09	-10.5	-13.0
ECS/028/04N	33	4.4	4.0	4.0	1.94	1.96	1.02	0.14	2.54	2.22	-19.4	-14.2
KIR/028/20N	33	4.4	2.9	3.4	1.37	1.59	-0.14	-0.42	2.36	0.64	6.9	-3.8
ITA/035/09N	33	4.4	3.4	3.9	2.20	2.67	1.00	-0.24	2.63	0.97	-6.4	-10.0
LOM/058/17N	33	4.4	2.9	2.7	1.60	1.66	0.36	-0.33	2.51	1.01	-7.4	-10.5
AFG/059/18N	33	4.4	2.9	3.4	2.18	1.81	0.36	-0.52	2.30	0.43	8.7	-0.8
YUG/063/21N	33	4.4	3.4	3.7	-	-	0.30	-0.52	2.45	0.86	-4.5	-7.0
NEJ/157/19N	33	4.4	3.0	2.8	1.79	1.70	0.55	0.13	2.82	1.56	-13.5	-16.6
KAM/186/13N	33	4.4	3.2	-	-	-	-0.33	-0.74	2.30	0.67	-1.5	-4.1
TUR/206/10N	33	4.4	3.1	3.5	2.04	2.06	0.33	-0.74	2.37	0.97	-9.2	-11.2

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 5 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS PAY	MS LOVE	LOG AR	LOG AL	LOG R30	LOG AUTO	LOG ENVC	DOM PER	SP.RAT R3/R1	SP.RAT R3/R2
KAM/004/02N	33	4.3	3.5	3.6	-	2.10	0.53	-0.46	2.23	0.75	-3.9	-3.6
KAM/009/14N	33	4.3	-	3.9	-	-	1.27	-1.00	2.72	0.88	-1.7	-4.6
TIR/042/12N	33	4.3	-	-	-	-	0.26	-0.01	2.29	0.72	-0.4	-1.7
ARC/C71/06N	33	4.3	-	-	-	-	-	-	-	-	-	-
CHI/154/20N	33	4.3	3.2	3.4	-	1.67	0.20	-2.12	2.29	0.78	-2.6	-8.4
KAM/157/04N	33	4.3	3.1	3.3	1.58	1.66	0.08	-0.25	2.30	0.91	-2.0	-5.2
BUR/160/16N	33	4.3	3.7	3.9	1.84	2.04	-0.07	-0.45	2.18	0.94	-2.6	-9.3
KUZ/163/23N	33	4.3	-	-	-	-	-0.54	-0.79	2.29	0.49	2.3	1.5
AUS/169/09N	33	4.3	2.9	2.6	1.38	1.62	-0.09	-0.40	2.13	1.29	-8.5	-14.4
TIR/170/04N	33	4.3	3.8	3.9	2.05	2.12	0.50	-0.20	2.56	0.86	-0.7	-10.4
KAM/173/10N	33	4.3	2.7	-	-	-	0.07	-0.24	2.30	0.89	-3.4	-6.6
CYP/180/08N	33	4.3	-	-	-	-	0.64	-0.14	2.37	1.15	-7.7	-7.8
SIN/197/04N	33	4.3	3.1	3.0	1.47	1.39	-0.03	-0.77	2.10	0.64	6.1	-3.7
SIN/221/01N	33	4.2	3.4	-	1.69	1.76	0.28	-0.17	2.37	0.72	12.5	-5.0
GRE/C02/09N	33	4.2	2.5	2.6	1.60	1.66	0.80	-0.57	2.56	0.87	-3.5	-5.4
SWR/007/20N	33	4.2	-	-	-	-	0.50	-0.24	2.45	0.70	-1.7	-1.1
KUR/022/01N	33	4.2	3.0	-	-	-	0.30	-0.59	2.23	0.61	0.0	-2.6
BAI/035/03N	33	4.2	3.4	3.1	1.77	1.66	1.11	-0.12	2.54	1.39	-14.0	-8.0
KUR/059/01N	33	4.2	-	-	-	-	-	-	-	-	-	-
PAK/059/05N	33	4.2	2.9	-	-	-	-0.40	-0.63	2.03	0.88	-0.4	-10.2
CKH/066/19N	33	4.2	-	-	-	-	1.86	0.02	2.80	0.80	-12.0	-9.1
OKH/068/02N	33	4.2	-	-	-	-	0.36	-0.17	2.46	0.70	-8.4	-7.0
IRA/155/09N	33	4.2	2.6	3.1	1.37	1.77	0.40	-0.91	2.43	0.71	-2.1	-8.2
IRA/156/03N	33	4.2	2.6	2.6	-	-	0.17	-0.23	2.60	1.43	-11.0	-5.8
SIB/001/15N	33	4.1	-	-	-	-	-	-	-	-	-	-

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 6 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG AR	LOG AL	LOG P30	LOG AUTO	LOG ENVO	DOM PER	SP.RAT P2/P1	SP.RAT S3/S2
KAM/032/10N	33	4.1	-	-	-	-	0.98	-1.29	2.46	1.13	-4.1	-7.3
IRA/041/16N	33	4.1	3.2	3.4	2.08	2.30	0.76	-0.43	2.20	0.66	5.2	-3.8
KUR/046/16N	33	4.1	3.0	2.7	1.62	-	1.12	-1.22	2.58	0.72	-10.5	-4.7
KAM/051/20N	33	4.1	3.2	-	1.80	-	1.30	-0.20	2.57	0.87	-13.0	-10.5
MON/053/01N	33	4.1	-	-	-	-	0.99	0.27	3.06	1.00	-17.0	-9.2
KAM/059/11N	33	4.1	-	-	-	-	-	-	-	-	-	-
KAM/063/00N	33	4.1	-	-	-	-	0.88	-0.04	2.40	0.75	-8.2	-3.5
KOM/063/08N	33	4.1	-	-	-	-	1.05	-0.36	2.53	1.29	-9.7	-6.6
KAS/071/13N	33	4.1	-	-	-	-	-0.48	-0.59	2.20	0.69	-6.0	-5.1
TIB/073/18N	33	4.1	-	-	-	-	1.17	0.24	2.79	1.10	-15.2	-7.4
TUR/160/12N	33	4.1	2.5	2.0	-	-	0.19	0.02	2.54	0.27	0.8	0.1
KAM/168/09N	33	4.1	-	-	-	-	1.16	0.09	2.50	0.87	-3.5	-3.0
KUR/171/22N	33	4.1	2.9	-	1.48	-	-	-	-	-	-	-
TUR/173/05N	33	4.1	3.3	3.1	2.22	2.01	0.40	-0.47	2.39	0.86	-8.4	-15.5
KAM/177/17N	33	4.1	3.3	3.6	1.90	2.14	-	-	-	-	-	-
KUR/001/18N	33	4.0	3.6	-	-	-	1.27	0.17	2.72	0.91	-15.2	-6.4
AUS/005/04N	33	4.0	2.6	2.8	2.05	2.04	1.43	-0.28	2.56	0.63	-4.2	-2.0
KOM/005/14N	33	4.0	-	-	-	-	-	-	-	-	-	-
CRE/026/12N	33	4.0	2.7	-	1.83	-	1.54	-0.66	2.76	1.62	-11.5	-11.5
ERS/028/21N	33	4.0	-	-	-	-	0.75	0.20	2.70	0.50	-5.5	-0.4
YUG/052/23N	33	4.0	-	-	-	-	0.03	-0.61	2.34	0.72	-2.8	-7.1
HIN/053/08N	33	4.0	3.2	3.1	2.05	1.83	-0.11	-0.97	2.20	0.67	-1.2	-5.6
KUR/056/22N	33	4.0	3.3	3.1	2.01	-	1.66	-0.16	2.51	0.92	-15.7	-13.8
IRQ/060/08N	33	4.0	2.7	3.2	-	2.04	0.35	-0.33	2.30	0.98	-8.1	-12.7
IRA/062/14N	33	4.0	-	-	-	-	1.15	0.01	2.46	0.56	-9.0	-7.4

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 7 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG AR	LOG AL	LOG P30	LOG AUTO	LOG ENVD	DOM PER	SP.RAT R3/R1	SP.RAT R3/R2
AFG/073/05N	33	4.0	-	-	-	-	-0.17	0.39	2.70	0.83	-12.2	-8.2
KUR/080/14N	33	4.0	-	-	-	-	0.14	-1.56	2.14	0.61	1.9	-1.5
KAM/156/07N	33	4.0	3.0	-	1.64	-	-0.67	-0.53	2.05	0.74	-2.8	-5.4
KU1/163/23N	33	4.0	-	-	-	-	0.22	-0.67	2.04	0.62	0.8	-4.9
IRA/182/20N	33	4.0	2.9	2.7	1.74	1.64	0.19	-0.29	2.43	0.86	-2.2	-11.0
IRA/187/16N	33	4.0	3.4	3.3	2.16	2.25	0.45	-0.39	2.39	1.02	-9.2	-10.4
GRE/200/13N	33	4.0	2.8	3.1	2.09	2.22	1.11	-0.05	2.92	0.88	1.9	-7.5
KAM/206/13N	33	4.0	3.3	-	1.97	-	0.26	-0.15	2.44	1.10	-10.4	-16.6
KAM/005/16N	33	3.9	3.2	3.3	-	-	1.02	-0.48	2.51	0.72	-2.2	-6.6
KOM/011/08N	33	3.9	-	-	-	-	0.01	-0.25	2.32	0.96	-10.0	-8.9
SIB/014/03N	33	3.9	3.2	3.1	2.28	2.27	1.55	-0.01	2.46	0.77	-8.0	-2.3
KUR/015/00N	33	3.9	-	-	-	-	-	-	-	-	-	-
IRA/029/09N	33	3.9	3.1	2.9	1.95	2.01	1.09	-0.19	2.50	0.60	-3.2	-1.9
IRA/041/09N	33	3.9	3.1	3.4	2.18	2.40	-0.25	-0.53	2.16	0.79	6.5	-6.1
KOM/044/22N	33	3.9	3.9	3.8	-	-	0.79	-0.30	2.38	0.74	-7.7	-5.7
SIN/051/10N	33	3.9	3.2	2.9	1.93	1.73	1.30	-0.09	2.62	0.75	-8.2	-7.7
KAM/066/06N	33	3.9	-	-	-	-	-	-	-	-	-	-
IRA/077/17N	33	3.9	-	-	-	-	-0.19	-0.72	2.43	1.11	-10.5	-11.5
CAU/079/03N	33	3.9	2.7	3.0	1.98	2.22	0.94	-0.59	2.71	1.05	-8.5	-8.0
SIN/154/06N	33	3.9	3.0	3.6	1.93	2.17	0.55	-0.48	2.57	0.78	6.0	-4.8
IRA/157/11N	33	3.9	2.9	3.4	2.02	2.21	-0.42	-0.11	2.19	0.59	-3.1	-5.9
KUR/170/09N	33	3.9	-	-	-	-	0.44	-0.51	2.26	0.56	2.3	1.4
KAM/180/14N	33	3.9	2.9	-	-	-	0.57	-0.58	2.34	0.69	0.1	-4.4
MED/199/03N	33	3.9	2.7	3.0	1.94	2.17	1.68	-0.06	2.69	1.04	-12.9	-6.6
MED/205/18N	33	3.9	2.9	2.6	1.94	1.79	-0.22	-0.28	2.55	0.77	-1.0	-4.3

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 8 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG A2	LOG AL	LOG P30	LOG AUTO	LOG ENVD	DOM PER	SP.RAT R3/R1	SP.RAT R3/R2
KUR/C09/14N	33	3.9	-	-	-	-	-	-	-	-	-	-
KAM/027/20N	40	3.9	-	-	-	-	1.15	0.15	2.73	1.00	-8.6	-4.3
KUR/028/23N	33	3.8	-	3.2	-	-	1.47	0.02	2.68	1.73	-11.0	-9.3
KUR/044/05N	33	3.9	-	-	-	-	0.50	-0.43	2.45	1.23	-11.0	-8.5
KUR/056/19N	33	3.9	-	-	-	-	1.07	-0.30	2.61	0.91	-10.7	-2.7
ERS/057/15N	33	3.9	-	-	-	-	1.44	-0.04	2.62	1.09	-17.9	-10.9
KUR/073/02N	33	3.8	-	-	-	-	1.93	0.53	2.91	0.75	-15.2	-5.5
KAM/165/04N	33	3.8	-	-	-	-	0.65	0.18	2.72	0.66	-7.6	-6.7
AEG/211/17N	33	3.8	3.6	3.4	2.31	2.37	0.23	-0.46	2.28	0.84	3.0	-5.6
KAM/054/19N	33	3.7	-	-	-	-	-	-	-	-	-	-
WRS/056/22N	33	3.7	-	-	-	-	1.31	0.20	2.68	1.26	-15.3	-7.4
KUR/066/09N	33	3.7	-	-	-	-	1.18	-0.26	2.66	1.02	-4.3	-5.1
KUR/070/06N	33	3.7	2.8	3.1	-	-	-0.09	-0.66	2.13	0.74	-5.7	-8.8
OKH/078/19N	33	3.7	-	-	-	-	1.45	-0.13	2.58	0.24	-13.5	-3.6
MON/153/11N	33	3.7	2.9	3.3	-	2.11	1.35	0.29	2.54	0.71	-5.3	-4.9
TSI/154/16N	33	3.7	3.5	3.9	2.55	2.68	0.40	-0.70	2.64	0.91	-5.3	-1.6
KUR/164/00N	33	3.7	-	-	-	-	-0.27	-1.10	2.52	0.44	-3.0	5.7
IRA/168/23N	33	3.7	3.0	3.2	2.15	2.22	-0.22	-0.14	2.41	0.72	-3.0	-1.2
ERS/172/09N	33	3.7	2.7	2.9	-	1.84	-	-	-	-	-	-
TUR/175/04N	33	3.7	2.8	3.1	2.37	2.41	-0.13	-0.48	2.35	0.94	-8.1	-10.6
YUG/177/04N	33	3.7	2.5	2.3	2.12	1.97	-0.16	-0.18	2.25	0.82	-2.9	-10.5
HIN/178/20N	33	3.7	2.9	2.8	2.09	-	-0.28	-0.75	2.33	0.69	0.1	1.3
CKZ/181/00N	33	3.7	2.4	-	1.81	-	-0.72	-0.57	2.46	0.88	-7.7	-6.1
KOM/C09/03N	33	3.6	-	-	-	-	-	-	-	-	-	-
KUR/033/09N	33	3.6	-	-	-	-	1.11	-0.33	2.49	1.62	-14.8	-14.0

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 9 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG AR	LOG AL	LOG P30	LOG AUTO	LOG ENVD	DOM PER	SP.RAT P3/P1	SP.RAT P3/P2
KUR/033/17N	33	3.6	-	-	-	-	1.08	-0.21	2.45	1.14	-8.4	-6.0
KAM/059/20N	33	3.6	-	-	-	-	-	-	-	-	-	-
KAZ/078/07N	33	3.6	3.0	-	2.96	-	1.17	-0.36	2.36	1.06	-14.0	-10.0
KAM/078/13N	33	3.6	-	-	-	-	1.32	-0.06	2.52	1.23	-17.0	-14.0
CKZ/153/01N	33	3.6	-	-	-	-	-	-	-	-	-	-
KUR/158/06N	33	3.6	-	-	-	-	-	-	-	-	-	-
IRZ/166/12N	33	3.6	-	-	-	-	0.04	-0.36	2.43	1.02	-5.9	-7.4
KAM/168/22N	33	3.6	-	-	-	-	-	-	-	-	-	-
KAS/172/15N	33	3.6	-	-	-	-	-0.06	-0.52	2.49	0.49	-6.3	-3.9
KAM/178/17N	33	3.6	-	-	-	-	-	-	-	-	-	-
TSI/180/03N	33	3.6	3.0	3.3	3.08	2.35	1.14	-0.20	2.46	1.17	-5.3	-6.2
KUR/186/21N	33	3.6	2.7	-	-	-	-	-	-	-	-	-
TIB/205/23N	33	3.6	-	3.5	-	2.29	-0.22	-0.38	2.51	1.23	-8.9	-8.9
IRA/213/21N	33	3.6	2.7	-	-	-	1.24	-0.33	2.53	0.77	-8.0	-8.3
KUR/055/18N	33	3.5	-	-	-	-	-	-	-	-	-	-
LOM/058/11N	33	3.5	-	-	-	-	1.04	0.11	2.58	1.00	-15.2	-12.2
ALM/062/19N	33	3.5	-	-	-	-	1.32	-0.02	2.53	0.66	-4.0	-4.0
BUL/068/22N	33	3.5	2.9	3.0	2.92	2.76	1.10	-0.22	2.43	1.51	-6.6	-6.9
KAS/077/23N	33	3.5	-	-	-	-	1.14	-0.21	2.60	1.14	-10.0	-6.6
SIN/154/05N	33	3.5	-	-	-	-	0.58	-0.24	2.63	0.62	-5.5	-1.3
KUR/197/17N	33	3.5	-	-	-	-	0.93	0.05	2.54	0.76	-13.2	-9.4
SIN/080/21N	33	3.4	-	-	-	-	1.15	0.05	2.47	0.60	-4.5	0.4
CRE/175/07N	33	3.4	3.4	3.6	2.34	2.35	0.56	-0.71	2.66	0.66	-3.6	-2.1
KOM/180/06N	33	3.4	-	-	-	-	-	-	-	-	-	-
KOM/183/02N	33	3.4	-	-	-	-	0.19	-0.55	2.45	0.79	-6.1	-5.5

TABLE A-2

DISCRIMINATION STATISTICS (EARTHQUAKES)
(PAGE 10 OF 10)

EVENT DESIGNATION	DEPTH	MB	MS RAY	MS LOVE	LOG AR	LOG AL	LOG P30	LOG AUTO	LOG ENVD	DOM PER	SP.RAT R3/R1	SP.RAT R3/R2
MED/199/16N	33	3.4	3.0	3.6	2.59	2.43	1.04	-0.08	2.55	0.62	-8.4	-6.5
KAM/057/09N	33	3.3	-	-	-	-	-	-	-	-	-	-
LOI/C58/08N	33	3.3	-	-	-	-	-	-	-	-	-	-
KAM/199/11N	33	3.3	-	-	-	-	-	-	-	-	-	-
YUG/067/05N	33	2.7	-	-	-	-	1.10	-0.12	2.44	0.62	-6.0	-7.3